SCHOTT
glass made of ideas

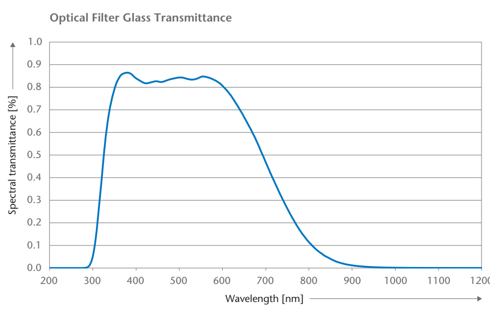
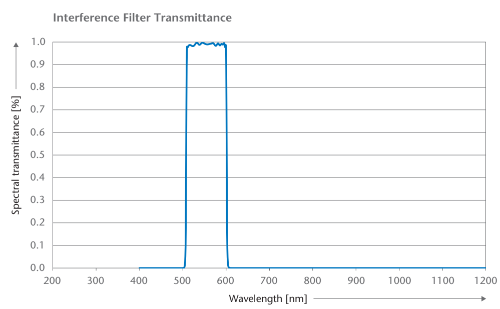
Optical Filters

2015

SCHOTT Advanced Optics, with its deep technological expertise, is a valuable partner for its customers in developing products and customized solutions for applications in optics, lithography, astronomy, opto-electronics, life sciences, and research. With a product portfolio of more than 120 optical glasses, special materials and components, we master the value chain: from customized glass development to high-precision optical product finishing and metrology.
SCHOTT: Your Partner for Excellence in Optics

SCHOTT Advanced Optics offers one of the world's largest portfolios of optical filter glasses and interference filters for a full spectral solution that meets your requirements. Both filter types are known for its specific characteristics and are used for special applications.

Here you find a description of the differences of the filter types on the example of a bandpass filter:

Characteristics of optical filters	Optical filter glasses	Interference filters
Transmittance	• Short wavelength: steep edge long wavelength, smooth edge • Not angle-dependent • Specific filter curves only	• Both wavelength edges: steep • Strong angle-dependent • Various filter curves available according to customer's specification
Blocking	High blocking achieved through glass thickness	High blocking achieved through multiple layers
Filter effect	Undesired light is absorbed	Undesired light is usually reflected, but absorption of layer materials can be exploited
Polarization of light	No modification of polarization state	Modification of polarization state dependent on incident angle and layer system design
Typical transmittance of optical filter glasses and interference filters	 	

SCHOTT Optical Filters

This **Folder** includes the following parts:

- Interference Filters & Special Filters – Description
- Interference Filters & Special Filters – Properties
- Optical Filter Glass – Description
- Optical Filter Glass – Properties

In addition, SCHOTT Advanced Optics offers product flyers addressing the following topics:

- Bandpass Filters
- BG60 & BG61
- Interference Filters
- Magnetron Sputtering extends range of interference filters
- Optical Filter Glass
- Scratch-resistant AR coating
- UV broadband DUG 11
- VERIL
- to be continued

Futhermore, technical datasheets of all filters and a filter calculation tool can be found on the SCHOTT Advanced Optics website.

SCHOTT interference filters

SCHOTT has been manufacturing interference filters since 1939 and is one of the inventors. Most of the interference filters are manufactured to meet customers' specifications. SCHOTT also uses optical filter glass, another main part of the filter glass portfolio, as substrate material for interference filters, leveraging the advantages of the benefits that the respective filter types offer.

Our **portfolio of interference filters** consists of:
- Longpass interference filters
- Shortpass interference filters
- Bandpass interference filters
- Neutral density thin-film filters
- Notch filters
- Beam splitters
- Polarizing beam splitters
- Black chrome coatings
- AR coatings: V-coating, broadband, multi-band, hard or scratch resistant
- Transparent conductive oxide coating
- Linear variable filters
- Dielectric (laser) mirrors
- Metallic mirrors

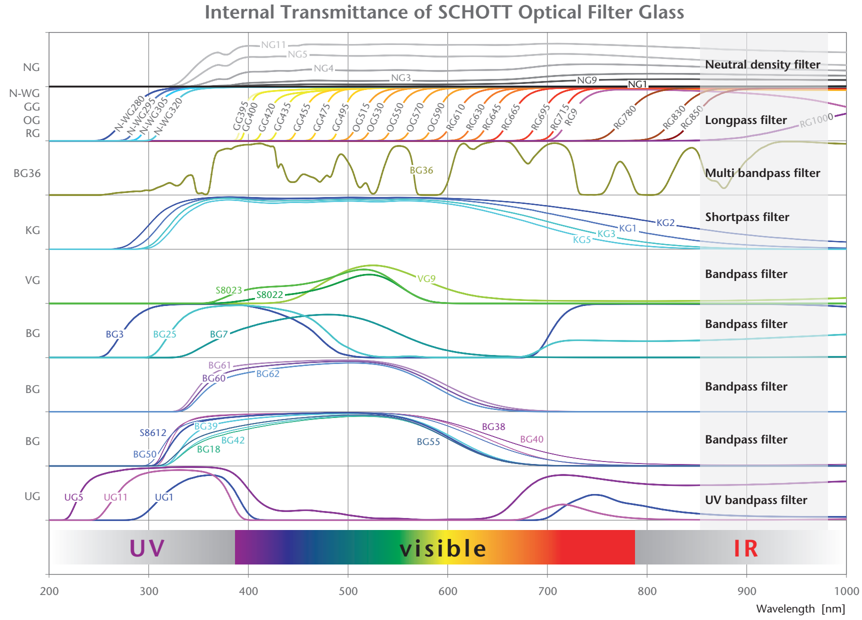
In addition, we also offer barrier coatings e.g.
- Humidity resistant
- Scratch resistant
- Anti-fingerprint

SCHOTT optical filter glasses

SCHOTT has been offering optical filter glasses since 1886. “Color glass with characteristic absorption,” as it was called in the catalogue of 1886, included didymium-phosphate glass, ceroxid-phosphate glass, and uranium oxide-phosphate glass. Over its long history, SCHOTT has further developed and optimized its **optical filter glass portfolio** and now offers:

- Longpass filters like GG, OG, or RG glass types
- Shortpass filters like KG glass types
- Bandpass filters like UG, BG, or VG glass types
- Neutral density filters like NG glass types
- Multi-band filters (BG36)

Internal Transmittance of SCHOTT Optical Filter Glass



SCHOTT optical filters as a combination of filter glasses and interference filters

A combination of both filter types enables a broad range of special filters, e.g.:

- Linear variable filters (VERIL) use filter glass and an additional interference filter coating
- Tristimulus filters use a combination of different types of filter glass
- Bandpass filters with broadband rejection are achieved by using filter glass together with an interference filter
- Optical filter glasses with a protective coating or additional interference coating

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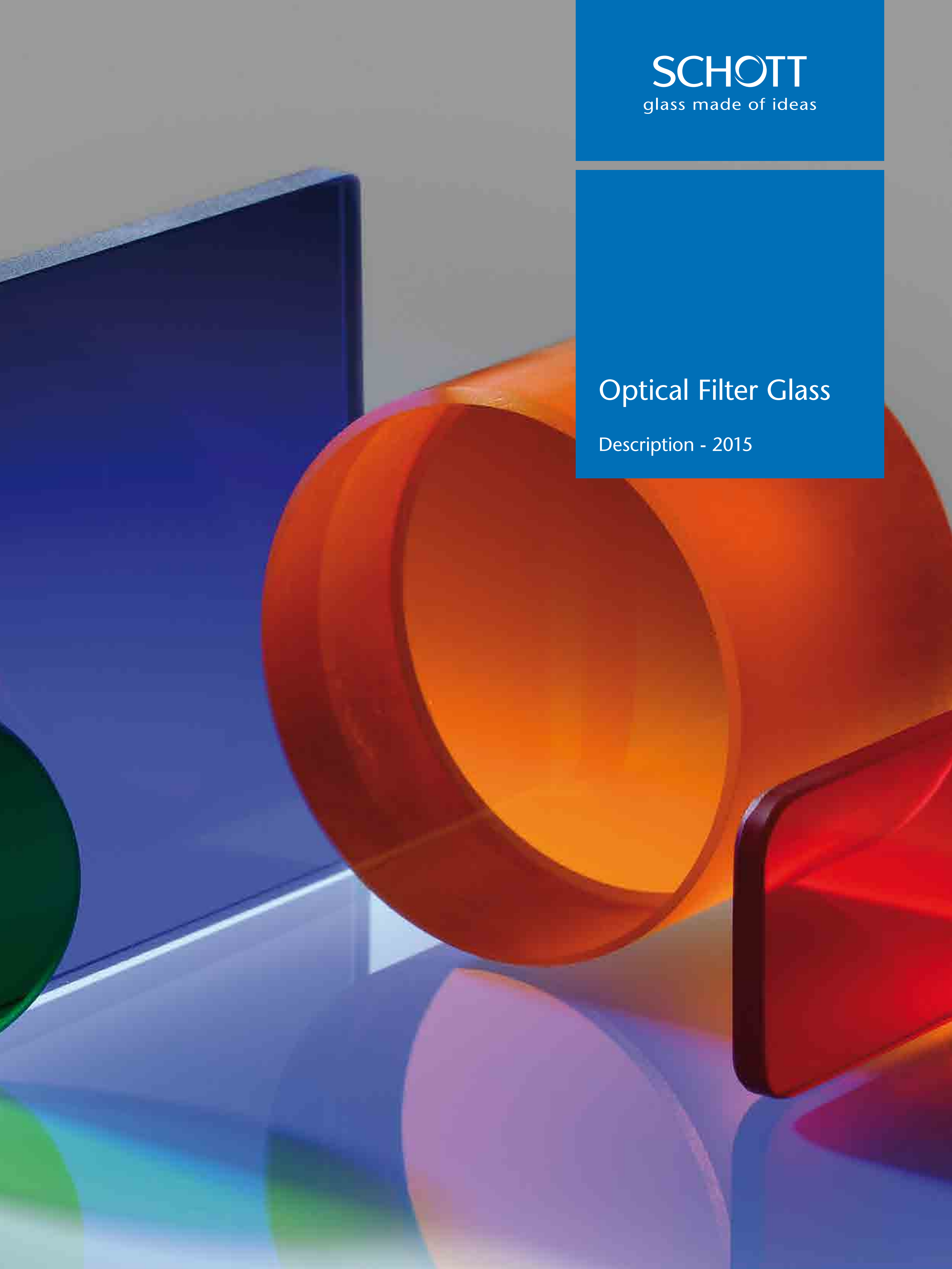
Optical Filter Glass

Description - 2015

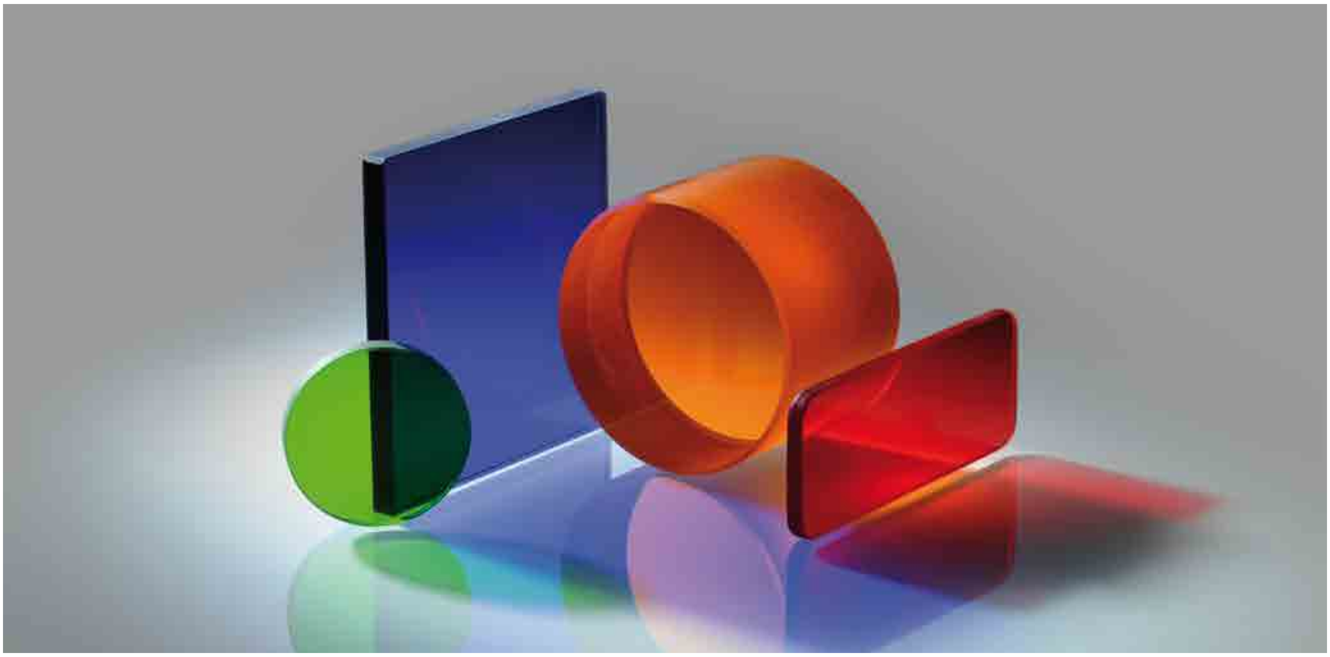


SCHOTT is an international technology group with more than 125 years of experience in the areas of specialty glasses and materials and advanced technologies. With our high-quality products and intelligent solutions, we contribute to our customers' success and make SCHOTT part of everyone's life.

SCHOTT Advanced Optics, with its deep technological expertise, is a valuable partner for its customers in developing products and customized solutions for applications in optics, lithography, astronomy, opto-electronics, life sciences, and research. With a product portfolio of more than 120 optical glasses, special materials and components, we master the value chain: from customized glass development to high-precision optical product finishing and metrology.

SCHOTT: Your Partner for Excellence in Optics.

Title
Various optical filter glasses that meet individual requirements and enable customized solutions.



Contents

1. Introduction

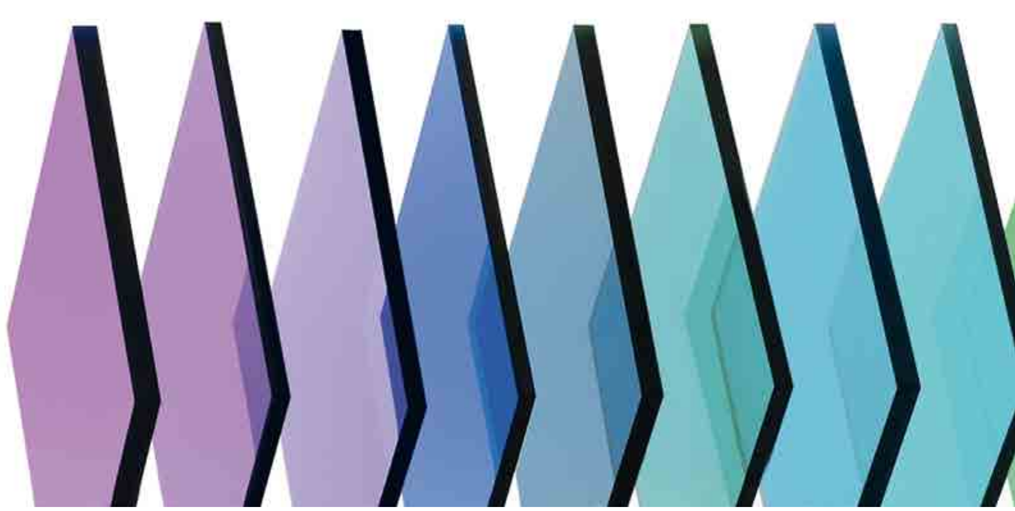
1.1 Foreword

SCHOTT Advanced Optics offers a wide range of optical filter glasses for any spectral solution to meet individual requirements and enable customized solutions.

Optical filter glass is known for its selective absorption in certain wavelength ranges. The optical filter glasses appear to be colored if their filter effect lies within the visible light spectrum. Filters from SCHOTT have been known for their particularly high quality, purity and outstanding properties for more than 100 years.

Currently, SCHOTT Advanced Optics' portfolio comprises more than 58 different optical filter glass types, all produced with great care using sophisticated industrial processes, that have the following advantages:

- High transmittance
- High blocking
- Filter curves hardly depend on the light angle
- Superior quality, reliability and durability
- No polarization effects
- Experience with high demands on surface quality, extremely thin and small tolerances when manufacturing complex glass types
- In-house optical and protection coating capabilities
- Ability to accommodate special requirements via close collaboration and development efforts between our customers and our application engineering team
- All colored filter glass types can be used as substrates for thin film coating to manufacture interference filters. Thus, specific advantages (absorption properties of a colored filter glass and the reflection properties of interference coatings) can be combined to one optical filter.



Various optical filter glasses that address the entire spectral range.

SCHOTT's optical filter glass portfolio is the product line of choice for system designers and optical engineers and is being constantly updated, reflecting the market needs. While advancing its capabilities, SCHOTT has continuously expanded its optical filter glass portfolio. Thus, now it contains special bandpass filters BG60, BG61 and BG62 as NIR-cut filter for imaging applications.

SCHOTT's optical filters are described in two brochures whereas this brochure named "Description" gives information about the most important criteria that pertain to the materials and characteristics of optical filters, and provides detailed technical information on each glass. The other brochure named "Properties" covers additional technical information.

If any information not covered in this brochure is needed, please contact a representative of our world wide sales team. Our experts will consult you and help in finding a solution for your challenge, as we believe that the close relationship to our customers is the key for successful work.

As we constantly strive to improve our products to your advantage through innovation and new technical developments, we reserve the right to change the optical and non-optical data in our Optical Filter Glass Brochure without prior notice. The new brochures were assembled with the utmost care; however, we assume no liability in the unlikely event that there are content or printing errors.

The release of this brochure replaces all previous publications.

January 2015

1.2 General information on listed data

All data listed in this brochure without tolerances are to be understood as reference values. Only those values listed in chapter 2 of the "Properties" brochure, under "Limit values of τ_i," "Tolerances of NVIS filters," "Tolerance ranges of τ_i," and "Tolerances for longpass filters" are guaranteed values. The graphically depicted internal transmittance curves serve as an initial overview to assist you in finding the most suitable filter type for your application.

Chapter 1 of this "Description" brochure contains an overview of SCHOTT's optical filter glass products, environmental aspects as well as specific information on optical filter glasses. Chapter 2 deals with nomenclature and classification of optical filter glass. Chapter 3 describes optical properties such as refractive index, spectral characterization or luminescence/fluorescence. Chapter 4 defines thermal and mechanical properties. Chapter 5 deals with chemical properties and chapter 6 gives an overview about internal quality. Chapter 7 and 8 cover topics such as further processing of optical filter glass and applications.

All of our filter datasheets and the filter calculation program can be easily accessed at www.schott.com/advanced_optics/optical-filter-glass, including filter glasses that are produced on special request only.

Unless otherwise indicated, all data is valid for a temperature of 20 °C.

Upon request, the reference values can be specified more closely and the guaranteed values can be adapted to meet your requirements, where possible.

1.3 Environmental aspects, hazardous substances, RoHS, ISO, REACh

SCHOTT Advanced Optics produces and distributes special materials and components in accordance with professional standards of our global Environmental, Health and Safety Management to prevent environmental pollution and to conserve natural resources and follows the procedures and philosophy of our global Quality Management System. Purchasing and handling of raw materials, the melting of batches, hot forming and coating is done strictly following established safety procedures and fulfilling requirements on material compliance.

All optical materials in this brochure comply with the requirements of the European Directive 2011/65/EU (RoHS). The optical materials featured in this brochure do not contain any mercury (Hg), chromium VI (CrVI) or the flame retardants PBB and PBDE whatsoever. Some of the optical filter glasses may contain lead or cadmium. They are in compliance with RoHS according to exemption 13b documented in ANNEX III of the directive 2011/65/EU.

In addition, all materials discussed in this brochure comply with the requirements of the European Regulation 2006/1907/EC (REACh: Registration, Evaluation and Authorization of Chemical Substances).

1.4 SCHOTT optical filter glass: product portfolio

The optical filter glass portfolio of SCHOTT consists of the following filter types in the wavelength range above 200 nm:

- **Bandpass filters** that selectively transmit a desired wavelength range;
- **Longpass filters** that block an undesired shorter wavelength range;
- **Shortpass filters** that block an undesired longer wavelength range; and
- **Neutral density filters** that exhibit nearly constant transmission, especially in the visible range.

Filter glass can be used in different thicknesses, which multiply the effects. In addition SCHOTT has a special expertise in cementing combinations of several filter glasses.

Special emphasis was placed on the qualitative and quantitative descriptions of glass and filter properties that are important to the user. For example, these include chemical resistance, bubble quality, and tolerances of transmission properties.

The curves in the "Properties" brochure group similar color glass types together to simplify your search for the most suitable filter glass for your application. These values are to be regarded as guidelines and should only serve to provide initial orientation.

2. Nomenclature and classification of optical filter glass

Our optical filter glasses are manufactured by using a wide variety of different ingredients and have numerous optical properties. For our portfolio a nomenclature is used that is closely related to the visual appearance of the optical filter glasses and their optical functions.

Nevertheless, many other properties are also related to the chemical composition of these glasses and the section 'classification by material' describes the three types of chemistry which apply to optical filter glasses.

2.1 Group names

Optical filter glasses are characterized by either their more or less selective absorption of optical radiation. The optical filters only appear colored if their filter function is within the visible spectral range.

Our optical filter glasses are structured according to the following group names:

Shortpass filter

KG Virtually colorless glass with high transmission in the visible and high absorption in the IR ranges (heat protection filters)

Longpass filter

GG Nearly colorless to yellow glass, IR-transmitting
OG Orange glass, IR-transmitting
RG Red and black glass, IR-transmitting
N-WG Colorless glasses with different cutoffs in the UV, transmitting in the visible and IR ranges

Bandpass filter

UG UV-transmitting glass
BG Blue, blue-green, and multiband glass
VG Green glass

Neutral density filter

NG Grey glass with uniform attenuation in the visible range

NVIS bandpass filter

NVIS Glass with a special color and high optical density for Near IR*

* NIR as defined in ISO 4007 is the wavelength range IR-A from 780 nm to 1.400 nm.

2.2 Classification by material

The various optical filter glass types can be divided into three classes based on their material composition:

2.2.1 Base glass

Colorless (transparent) optical glass that has the cutoff in a different location in the UV (see N-WG glasses).

2.2.2 Ionically colored glass

Ions of heavy metals or rare earths can influence the coloration of glasses in true solution. This coloration depends on the nature and quantity of the coloring substances, the oxidation state of the coloring substances, and the base glass composition (see UG, BG, VG, NG, and KG glasses as well as glass types RG9, RG1000, S8612 and NVIS glasses).

2.2.3 Colloidally colored glass

The colorants in these glasses are generally rendered effective by secondary heat treatment ("striking") of the initially (nearly) colorless glass. Particularly important glasses in this class include the yellow, orange, red, and black filter glasses with their steep absorption edges. As with the ionically colored glasses, their color is dependent upon the type and concentration of the colorants, the base glass, and, to a large extent, their thermal history during secondary heat treatment (see GG, OG and RG glasses with the exception of RG1000).

The optical filter glass type RG9 presents a mixture of an ionically colored and colloidally colored glass. The shortwave absorption edge results from the colloidal glass character, and the longer wavelength behavior is determined by ionic coloring.

2.2.4 Reproducibility of transmission

The spectral properties of the base and ionically colored optical filter glasses are nearly constant within the individual melts. Based on slight deviations in the properties and pureness of the raw materials and batch composition, deviations can occur from melt to melt. The colloidally colored glasses also exhibit deviations within a melt due to technically unavoidable temperature gradients during the striking process.

In the "Properties" brochure the manufacturing based maximum deviations of transmission are listed for each glass type (refer to "Limit values of τ_i," "Tolerance ranges of τ_i," and "Tolerances for longpass filters"). These spectral properties are measured and documented for each production batch. Through selection and reservation of suitable melts and through variation in the optical filter glass thickness, tighter tolerances can be achieved.

3. Optical properties

The following chapter covers the important optical definitions and formulas that are used to describe the optical properties of the optical filter glasses. In addition, the relevant optical features of the optical filter glasses are explained.

3.1 Refractive index

In imaging optics, light refraction and its spectral dependence (dispersion) are the most important properties; they are determined by the wavelength-dependent refractive index $n(\lambda)$. However, optical filter glasses are optimized for their characteristic spectral transmission, thus, the refractive indices are basically listed as reference values to two decimal points only.

3.2 Reflection loss at glass-air interface

At the glass-air interface a part of the incident air beam will be reflected. This reflection loss R is known as "Fresnel loss" and is a function of the refractive index of air ($n_{air} = 1$) and the refractive index of glass ($n(\lambda)$). Because of the dependence of the refractive index on the wavelength, the reflection loss R is also dependent on the wavelength and can be calculated for a single glass-air interface as follows:

$$R = \left(\frac{1 - n(\lambda)}{1 + n(\lambda)}\right)^2$$

Due to reflection that occurs where the two glass surfaces of a filter come into contact with air, the radiation is attenuated by both interfaces. The resultant reflection loss is described by the reflection factor P(λ). P is the Greek letter "Rho". Under the constraint of incoherent radiation, perpendicular incidence, and considering multiple reflections, **equation 1** applies.

$$P(\lambda) = \frac{2n(\lambda)}{n^2(\lambda) + 1} \tag{1}$$

3.3 Transmittance and internal transmittance

Optical radiation filters are characterized by their transmission which is strongly dependent on the wavelength. Thus, the most important filter data is the spectral transmittance $\tau(\lambda)$ or the spectral internal transmittance $\tau_i(\lambda)$. The difference between the two is described below:

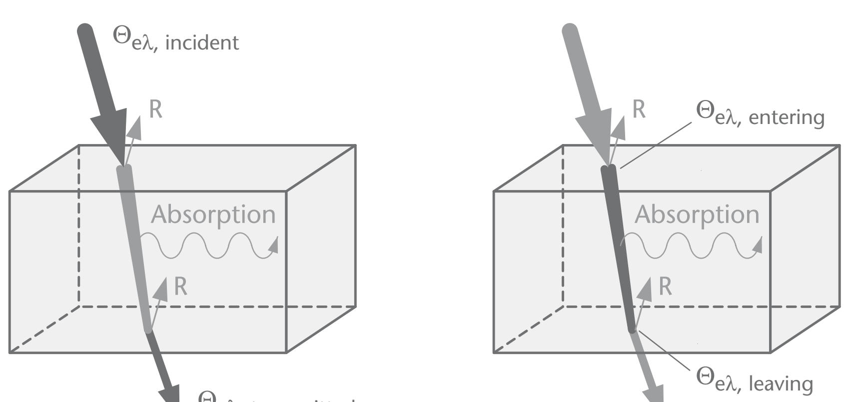


Fig. 3.1
Definition of spectral transmittance (left) and internal spectral transmittance (right).

Definition of **spectral transmittance**:

$$\tau(\lambda) = \frac{\Theta_{e\lambda,\text{transmitted}}}{\Theta_{e\lambda,\text{incident}}} \quad (2)$$

The spectral transmittance $\tau(\lambda)$ in **equation 2** is the ratio of the transmitted (energetic) spectral flux $\Theta_{e\lambda,\text{transmitted}}$ to the incident (energetic) spectral flux $\Theta_{e\lambda,\text{incident}}$. Hence $\tau(\lambda)$ describes the transmittance of the absorbing glass filter considering the reflection losses at the front and rear sides of the filter. The spectral transmittance can be measured easily. It is important to note that, in case of plano-parallel geometry of the substrate, the incident spectral flux and the transmitted spectral flux have the same wavelength λ and they are both traveling in the same direction. In the special case of luminescence (chapter 3.8) there is additional emerging flux present which has different wavelengths and which is diffuse. This additional energetic flux must be eliminated from the measurement of the transmittance $\tau(\lambda)$.

Definition of **internal spectral transmittance:**

$$\tau_i(\lambda) = \frac{\Theta_{e\lambda,\text{leaving}}}{\Theta_{e\lambda,\text{entering}}} \quad (3)$$

The spectral internal transmittance $\tau_i(\lambda)$ in **equation 3** is the ratio of the emerging spectral radiant flux $\Theta_{e\lambda,\text{leaving}}$ to the radiant flux $\Theta_{e\lambda,\text{entering}}$, which has just penetrated into the glass. The internal transmittance $\tau_i(\lambda)$ describes the transmittance of the absorbing filter glass without considering reflection losses. However, the internal transmittance cannot be measured directly. There are two formulas for converting spectral internal transmittance into transmittance and vice versa:

Using R: $\tau = \frac{(1-R)^2\tau_i}{1-\tau_i^2 R^2}$ and $\tau_i = -\frac{(1-R)^2}{2R^2\tau} + \sqrt{\frac{(1-R)^4}{4R^4\tau^2} + \frac{1}{R^2}}$

Or using the reflection factor $P(\lambda)$:

$$\tau(\lambda) = P(\lambda) \cdot \tau_i(\lambda) \quad (4)$$

Equation 4 is used to relate internal transmittance and transmittance in our brochure and our calculation tool.

The Bouguer-Lambert law **(equation 5)** applies to perpendicular radiation incidence and assuming homogeneous absorption. It describes the dependence of the spectral internal transmittance on glass thickness.

$$\tau_{i,d_1}(\lambda) = \tau_{i,d_2}(\lambda)^{d1/d2} \quad (5)$$

$\tau_{i,d_1}(\lambda)$: Internal transmittance at the wavelength λ and with filter thickness d_1.
$\tau_{i,d_2}(\lambda)$: Internal transmittance at the wavelength λ and with filter thickness d_2.

Generally, the description for the dependence of the spectral transmittance on thickness is:

$$\tau_{d1}(\lambda) = P(\lambda) \cdot \tau_{i,d2}(\lambda)^{d1/d2} \tag{6}$$

By using **equation 6**, the thickness d_1 can be derived from a given desired transmittance $\tau_{d_1}(\lambda)$ by **equation 7**.

$$d_1 = d_2 \frac{\lg(\tau_{d1}(\lambda)) - \lg(P(\lambda))}{\lg(\tau_{i,d2}(\lambda))} \tag{7}$$

3.4 Derived optical filter data

In addition to transmittance $\tau(\lambda)$ and internal transmittance $\tau_i(\lambda)$, the following filter characteristics derived from them are useful:

3.4.1 Spectral optical density

$$D(\lambda) = \lg \frac{1}{\tau(\lambda)} \tag{8}$$

3.4.2 Spectral absorbance (extinction)

$$A(\lambda) = \lg \frac{1}{\tau_i(\lambda)} \tag{9}$$

3.4.3 Spectral diabatie

$$\Theta(\lambda) = 1 - \lg\left(\lg \frac{1}{\tau_i(\lambda)}\right) = \lg \frac{10}{A(\lambda)} \tag{10}$$

Note: For optical filter glass the spectral diabatie is calculated using the internal transmittance τ_i. For interference filters, which have special reflectance properties, the spectral diabatie is derived using the spectral transmittance τ.

3.4.4 Luminous transmittance

$$\tau_{v,D65} = 100\,\% \frac{\int_{\lambda = 380\,nm}^{780\,nm} \tau(\lambda)\, S_{D65}(\lambda)\, V(\lambda)\, d\lambda}{\int_{\lambda = 380\,nm}^{780\,nm} S_{D65}(\lambda)\, V(\lambda)\, d\lambda} \tag{11}$$

The luminous transmittance (according to DIN EN ISO 4007:2012-09) is the ratio of the luminous flux transmitted by a filter with spectral transmittance $\tau(\lambda)$ to the incident luminous flux $S_{D65}(\lambda)$ of the light source D65 for photopic vision $V(\lambda)$.

3.5 Internal transmittance curves

The $\tau_i(\lambda)$ values for the appropriate reference thicknesses are **presented** graphically in the "Properties" brochure. The wavelength from 200 nm to 1200 nm is shown as the abscissa. The internal transmittance $\tau_i(\lambda)$ is shown as the ordinate in a special log-log-scale (see spectral diabatie). Presented this way, the curved shapes are independent of the thickness of the optical filter glass.

The values are reference values and therefore should only serve for initial orientation purposes.

3.6 Spectral characterization of optical filters

Optical filters are described by their spectral characteristics and can be divided into several groups. The most important types are defined and explained below.

3.6.1 Longpass filters

Long wavelengths can pass through a longpass filter. A longpass filter is characterized by the fact that a range of low transmission (blocking range) in the short wavelength region is joined to an area of high transmission (pass band) in the long wavelength region (see **figure 3.2**).

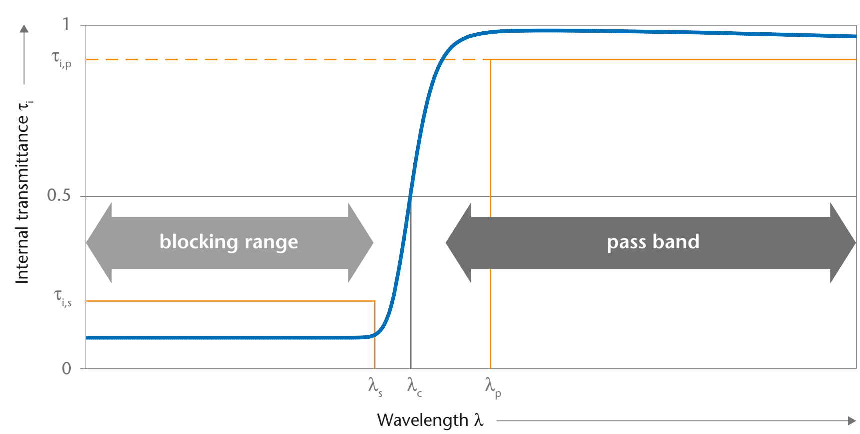


Fig. 3.2
Longpass filter

The important properties applicable to optical filter glasses:

λ_c: Edge wavelength or cutoff wavelength at which point the spectral internal transmittance has a value of 0.5.

λ_s: The limit of the blocking range. Below this wavelength, the internal transmittance has a value below $\tau_{i,s}$ for a certain spectral region.

λ_p: The limit of the pass band. Above this wavelength, the spectral internal transmittance does not fall below $\tau_{i,p}$ within a certain spectral range. The pass band can be divided into several sub-ranges, e.g. into two ranges with $\tau_{i,p1} = 0.90$ and $\tau_{i,p2} = 0.97$.

3.6.2 Shortpass filters

Short wavelengths can pass through a shortpass filter, while long wavelengths are blocked. Typically, the slope at the transition between pass band and blocking range of a longpass filter is much steeper than the slope of a shortpass filter.

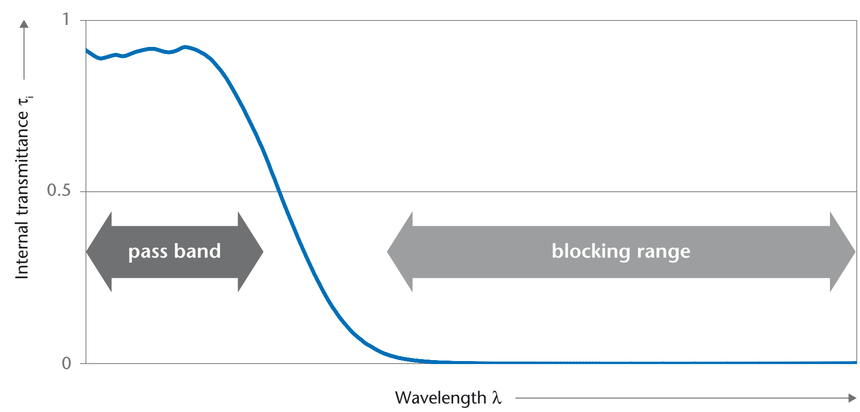


Fig. 3.3
Shortpass filter

3.6.3 Bandpass filters

Bandpass filters selectively transmit a desired wavelength range. They are characterized by the fact that they connect a region of high transmission (pass band) and shorter and longer wavelength regions with low transmission (blocking ranges).

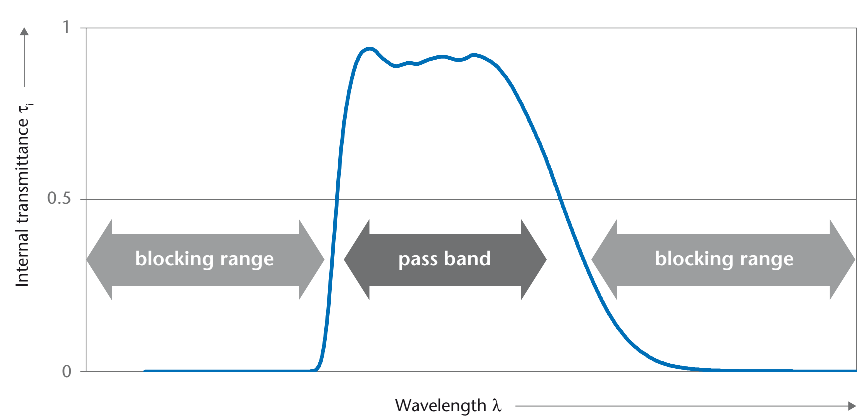


Fig. 3.4
Bandpass filter

3.6.4 Neutral density filters

Neutral density filters exhibit nearly constant spectral transmittance in the range of the visible light, for example from 400 nm to 800 nm, and are therefore only slightly wavelength dependent. Neutral density filters are therefore perfectly grey in color.

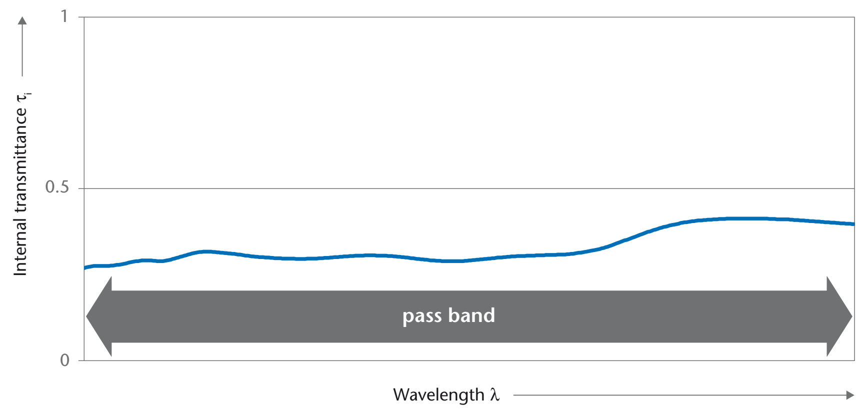


Fig. 3.5
Neutral density filter

3.6.5 Overview of transmittance properties

The figure **3.6** (see next page) depicts the transmittance properties of all our optical glass filters. In order to obtain a clear overview, the curves are sorted into nine groups and the scale of transmittance is linear.

3.7 Dependence of spectral transmission on temperature

The cutoff wavelength λ_c of longpass filters shifts to higher wavelengths with increasing temperature. In the "Properties" brochure, the temperature coefficient of the edge wavelength $\Delta\lambda_c/\Delta T$ [nm/K] is listed for all longpass filters. These are average values in the temperature range from 10 °C to 90 °C.

For the bandpass filters and filters with shallow slope, the changes in spectral transmittance as a function of temperature are relatively small. Additional information can be provided upon request.

3.8 Luminescence / fluorescence

The more or less pronounced luminescence of the optical filter glasses is only interesting for practical purposes if these filters are to be used to measure the luminescence of materials. Here, the application of optical filter glasses as excitation filters, i.e. for spectral isolation of the exciting radiation, presents no problem in most cases.

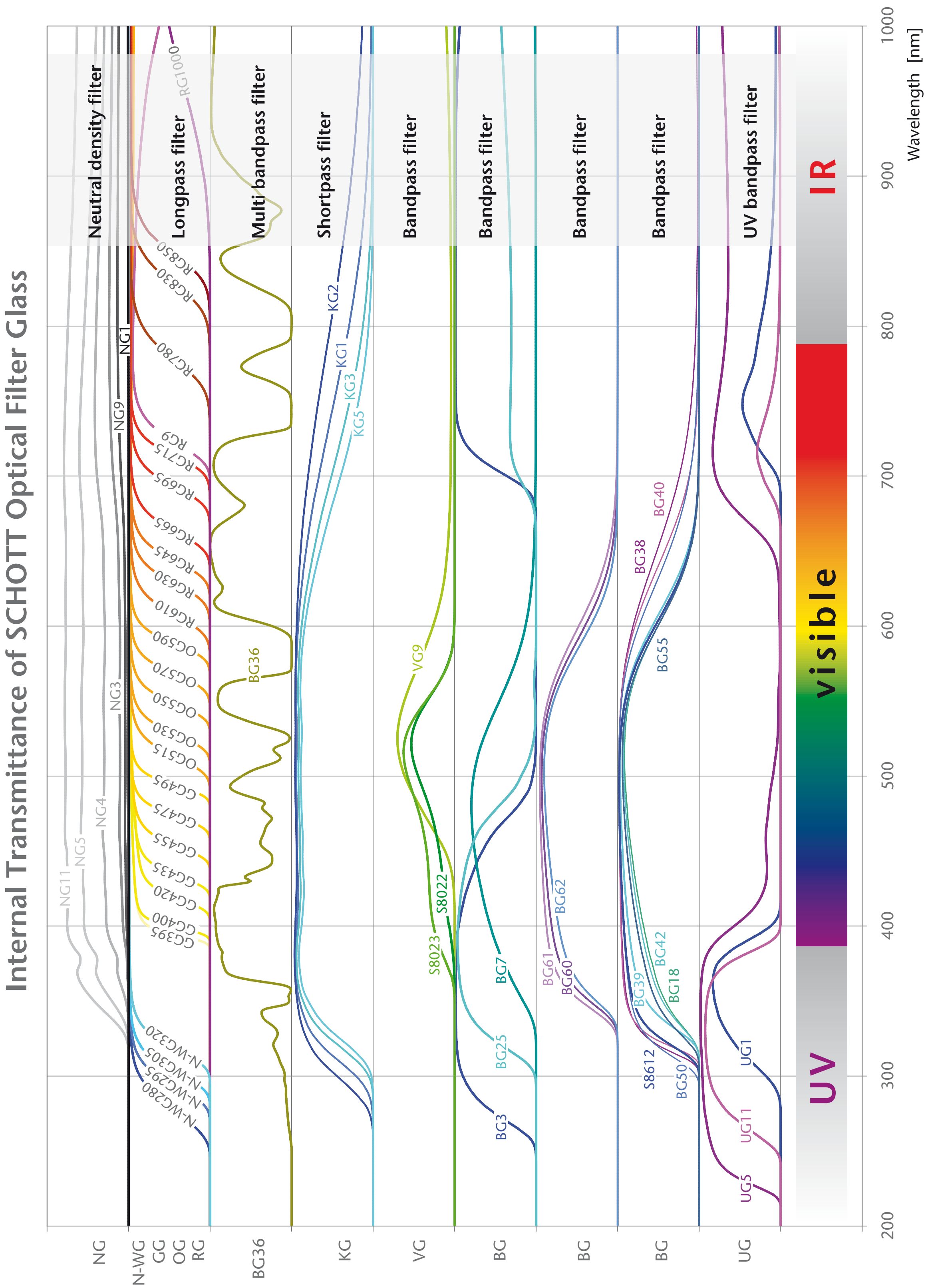


Fig. 3.6
SCHOTT optical filter glass portfolio: The transmittance of all filters is depicted in 9 groups, where the ordinate is in linear scale.

3.9 Color

Color is a sensation perceived by the human eye when observing an illuminated filter glass. It is a function of the spectral transmission of the filter and the spectral distribution of the illuminating light source. Color stimulus is measurable and is defined by three numerical values (X, Y, Z) in accordance with color metric conventions set forth by the CIE (see publication CIE N° 15.2 (1986)). The first value is the brightness (standard tristimulus value) Y and the other two values define the color locus. There are two possibilities to define the color locus F (see **figure 3.7**): Either the chromaticity coordinates x and y, or the dominant wavelength λ_d and the excitation purity $P_e = \overline{DF} : \overline{DS}$.

The following values are listed in the datasheets for our "colored" filter glasses, which exclude black, neutral density, and clear glasses: x, y, Y, λ_d, and P_e.

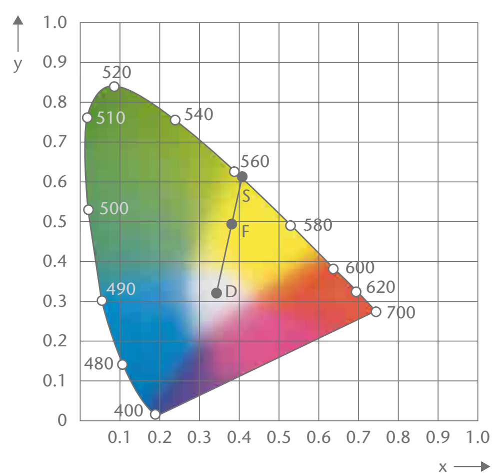


Fig. 3.7
The color of optical filter glasses according to the definition of CIE 1931
D: Color locus of the radiation source, for example D65
S: Point at which the extension $\overline{DF}$ intersects the spectrum locus at λ_d

These apply to:

- Optical filter glass thicknesses of 1, 2, and 3 mm
- Illumination with the illuminants:
  – Standard illuminant A (Planckian radiator at 2856 K), incandescent lamp
  – Planckian radiator at 3200 K, halogen lamp light
  – Standard illuminant D65, standard daylight
- 2°-standard observer
- 20 °C temperature

The tristimulus values listed in the datasheets are reference values only.

Chromaticity coordinates relevant to Night Vision Imaging Systems (NVIS) compatibility are described in terms of the UCS coordinates u' and v'. These coordinates are directly related to the CIE[1] x and y coordinates by way of the following formula:

$$u' = \frac{4x}{-2x + 12y + 3} \text{ and } v' = \frac{9y}{-2x + 12y + 3} \quad (12)$$

where:

u', v' = 1976 UCS chromaticity coordinates according to CIE
x, y = 1931 chromaticity coordinates according to CIE

Additionally, the UCS chromaticity coordinates can also be expressed in terms of the tristimulus values X, Y and Z:

$$u' = \frac{4X}{X + 15Y + 3Z} \text{ and } v' = \frac{9Y}{X + 15Y + 3Z} \quad (13)$$

For illumination systems to be designated as NVIS Green A, NVIS Green B, NVIS Yellow, NVIS Red, or NVIS White compatible, the chromaticity of the illumination system must adhere to the following formula:

$$(u' - u'_0)^2 + (v' - v'_0)^2 \leq r^2 \quad (14)$$

where:

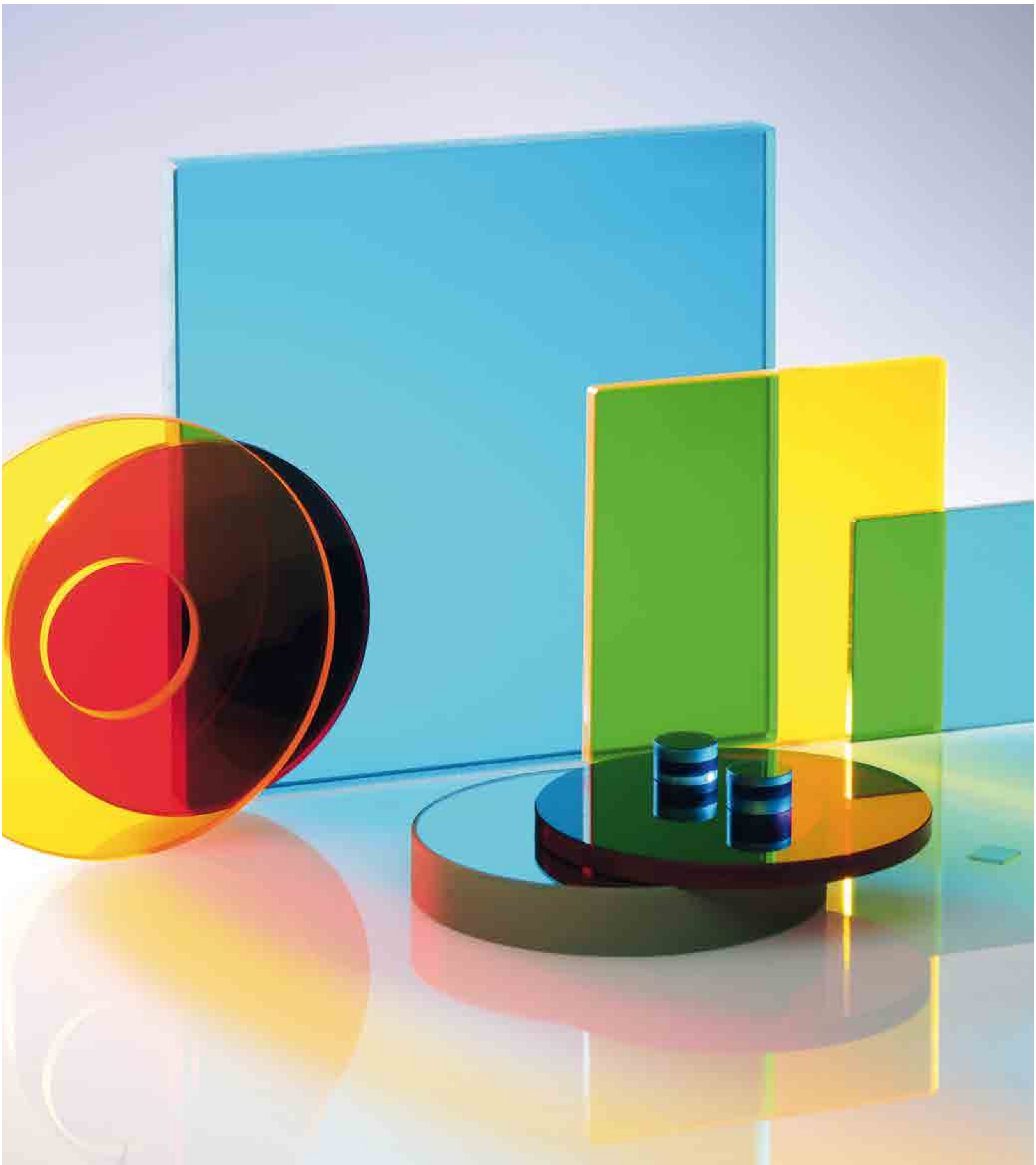
u'_0 and v'_0 = 1976 UCS chromaticity coordinates of the center point of the specified color area
u' and v' = 1976 UCS chromaticity coordinates of the color locus of the illumination system (e.g. combination of filter and light source)
r = radius of the permissible circular area on the 1976 UCS chromaticity diagram for the specified color

3.10 Brightness / photopic transmittance

The tristimulus value Y (Brightness) may be replaced by the expression “Photopic Transmittance.” The relation between Y and Photopic Transmittance is simply a factor of 100 %.

Example: Brightness Y = 57 corresponds to Photopic Transmittance = 57 %

[1] Commission Internationale de l’Eclairage, Vienna, Austria. http://www.cie.co.at/



Optical filter glasses in different shapes and supply forms (coated, cemented, etc.).

4. Thermal and mechanical properties

In order to develop an assortment of optical filter glasses covering the largest possible spectral area, some with extreme filtering properties, numerous colorants with different concentrations and many different base glasses had to be developed. In the "Properties" brochure the following important properties are listed for each optical filter glass type, mostly on a quantitive basis. These are typical values. Exact measurements can be performed upon request.

4.1 Mechanical density ρ [g/cm^3]

The mechanical density ρ is defined as the quotient of mass and volume. Most optical filter glass types have a density between 2.4 and 2.8 g/cm^3.

4.2 Strength

The strength of glass is not only a material property, but also a function of the surface quality. This means that the strength is highly dependent on the surface finish and edge quality of a component. Thus, small scratches can lower the strength significantly. Our technical information "TIE 33: Design strength of optical glass and ZERODUR®"[2] provides additional information on the strength of glass and relevant design issues.

4.3 Thermal toughening

In most cases an absorbing optical filter glass is heated unevenly by the illuminating radiation. The low thermal conductivity of optical filter glass prevents rapid thermal equilibrium.

Thus, temperature gradients arise both between the front and the rear side and especially between the center and the edges of the optical filter glass. This produces flexural stresses within the optical filter glass based on the thermal expansion.

An improved resistance to larger temperature gradients or rapid temperature changes and an increase in the flexural strength can be achieved through thermal toughening of the optical filter glass. The improved thermal resistance of toughened optical filter glass causes a slight deformation and possibly a slight change in the spectral values.

Thermal toughening is required for optical filter glasses placed in front of intense light sources in order to increase their breaking strength. It must be assured that the temperature of the glass does not exceed a temperature of (Tg – 300 °C), or, for short periods, (Tg – 250 °C). Otherwise, thermal toughening will weaken as a function of temperature and time. The transformation temperature Tg is listed for each color glass type in the "Properties" brochure.

[2] Technical information (TIE) can be downloaded from the "Community" section of our website.

Already at the stage of designing lamps, adequate measures have to be taken to minimize temperature gradients – especially between the center and the edges of the glass plate (uniform illumination). When installing filters into mounts and / or lamp housings, it must be assured that no additional mechanical forces are applied on the glasses. Direct metal-to-glass contact must be avoided, insulating intermediate layers made of suitable materials are recommended.

4.4 Transformation temperature Tg [°C]

The transformation range of an optical filter glass is the boundary region between brittle and liquid behavior. It is characterized by the precisely determined transformation temperature Tg which is defined according to ISO 7884-8. As a rule of thumb, a maximum temperature T_{max} = Tg – 200 °C should not be exceeded during filter operation as the glass and filter properties may otherwise change permanently.

4.5 Thermal expansion α [10^{-6}/K]

The coefficient of thermal expansion (CTE or α) gives the relative change in the length of a glass when it is exposed to heat. This is a function of the temperature, but the dependence is low, therefore it can be approximated using a linear function, which is most accurate for a limited temperature regime:

$\alpha_{-30/+70\,°C}[10^{-6}/K]$	denotes the linear coefficient of thermal expansion in the range of [–30 °C; + 70 °C]
$\alpha_{20/300\,°C}[10^{-6}/K]$	denotes the linear coefficient of thermal expansion in the range of [20 °C; 300 °C]

The second value is approximately 10 % higher than the first.

For some glasses the linear coefficient of thermal expansion is given for the temperature regime of [20 °C; 200 °C] due to their low transformation temperature.

5. Chemical properties

For various chemical requirements, especially during different processing steps, we use the resistance classes that apply to optical glass. The greater the resistance of the glass, the lower the class number. The resistance classes for all optical filter glasses are listed in the "Properties" brochure.

Exact descriptions of the individual test procedures are available upon request.

5.1 Stain resistance

The test procedure provides information on possible changes in the glass surface (stain formation) under the influence of slightly acidic water (for example perspiration, acidic condensates) without vaporization.

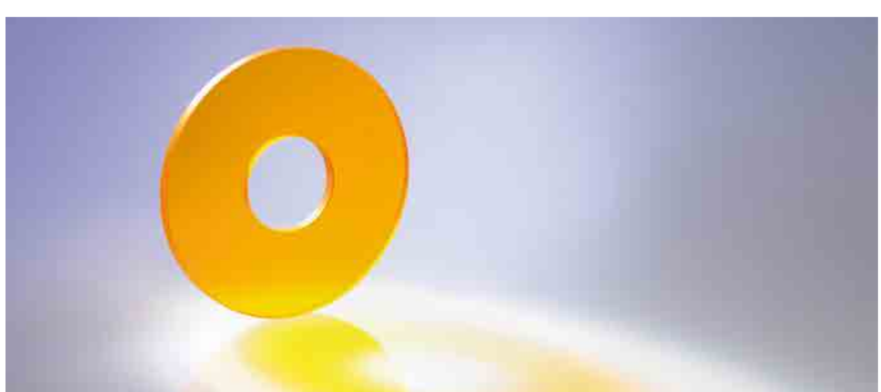
The stain resistance class is determined according to the following procedure: The plane polished glass sample to be tested is pressed onto a test cuvette, which has a spherical depression of max. 0.25 mm depth containing a few drops of test solution I or II.

Test solution I: Standard acetate pH = 4.6
Test solution II: Sodium acetate buffer pH = 5.6

Interference color stains develop as a result of decomposition of the surface of the glass by the test solution. The measure for classifying the glasses is the time that elapses before the first brown-blue stain occurs at a temperature of 25 °C. This change in color indicates a chemical change in the previously defined surface layer of 0.1 µm thickness.

Table 5.1
Classification of optical filter glasses into stain resistance classes FR 0–5.

Stain Resistance Classes FR	0	1	2	3	4	5
Test solution	I	I	I	I	II	II
Time (h)	100	100	6	1	1	0.2
Color change	no	yes	yes	yes	yes	yes



CNC machined filter glass.

5.2 Acid resistance

Acid resistance according to ISO 8424 classifies the behavior of glass surfaces that come in contact with large quantities of acidic solutions (from a practical standpoint for example, perspiration, laminating substances, carbonated water, etc.).

Acid resistance is denoted by using a two or a three digit number. The first or the first two digits indicate the acid resistance class SR. The last digit (separated by a decimal point) denotes the change in the surface visible to the unaided eye that occurs through exposure (see section 5.4).

The time t required to dissolve a layer with a thickness of 0.1 μm serves as a measure of acid resistance. Two aggressive solutions are used in determining acid resistance. A strong acid (nitric acid, c = 0.5 mol/l, pH 0.3) at 25 °C is used for the more resistant glass types. For glasses with less acid resistance, a weak acidic solution with a pH value of 4.6 (standard acetate) is used, also at 25 °C.

Class SR 5 forms the transition point between the two groups. It includes glasses for which the time for removal of a layer thickness of 0.1 μm at a pH value of 0.3 is less than 0.1 hour and at a pH value of 4.6 is greater than 10 hours.

Table 5.2
Classification of optical filter glasses into acid resistance classes SR 1–53 (ISO 8424).

Acid Resistance Classes SR	1	2	3	4	5	51	52	53
pH value	0.3	0.3	0.3	0.3	0.3 | 4.6	4.6	4.6	4.6
Time (h)	> 100	10–100	1–10	0.1–1	< 0.1 | > 10	1–10	0.1–1	< 0.1

5.3 Alkali resistance

Alkali resistance according to ISO 10629 indicates the sensitivity of optical filter glasses in contact with warm alkaline liquids, such as cooling liquids in grinding and polishing processes.

Alkali resistance is denoted using two digits separated by a decimal point. The first digit lists the alkali resistance class AR and the decimal indicates the surface changes visible to the unaided eye that occur through exposure.

The alkali resistance class AR indicates the time required to remove a 0.1 μm thick layer of glass in an alkaline solution (sodium hydroxide, c = 0.01 mol/l, pH = 12) at a temperature of 50 °C.

The layer thickness is calculated based on the weight loss per surface area and the density of the glass.

Table 5.3
Classification of optical filter glasses into alkali resistance classes AR 1–4 (ISO 10629).

Alkali Resistance Classes AR	1	2	3	4
Time (h)	>4	1–4	0.25–1	<0.25

5.4 Identification of visible surface changes

Meaning of the digits used for the classification of acid and alkali resistance:

.0 no visible changes
.1 clear, but irregular surface
.2 interference colors (light, selective leaching)
.3 firmly adhering thin white layer (stronger, selective leaching, cloudy surface)
.4 loosely adherent, thicker layers, for example, insoluble reaction products on the surface (this can be a projecting and / or flaking crust or surface; strong attack)

5.5 Resistance against humidity

After a certain amount of time, the surface of highly sensitive glasses exhibits a slightly cloudy residue. Initially, this residue can be removed using glass polishing compounds. More severe attacks ruin the surface polish quality, however. This effect is caused by humidity. With respect to this behavior, the color filter glasses can be classified into three groups:

Group 1
No substantial surface change occurs in most of the optical filter glass types. These types are not identified specially in the "Properties" brochure.
A change in the surface is only possible under extreme conditions, if subjected to a continuous spray of sea water, or if used in rain or water.

Group 2 Symbol:
For the optical filter glass types BG18, BG40, BG50, BG55 and all KG glass types, there is virtually no long-term change when used and stored in moderate climates or in closed work and store rooms (constant temperature below 35 °C, relative humidity less than 80 %). A desiccant should be used if the possibility of wetting exists. For use and storage in open air and tropical climates, it is advisable to apply a protective coating which SCHOTT can provide upon request.

Group 3 Symbol:
For the optical filter glass types BG42, UG5, UG11, BG39, S8612, S8022 and S8023 a change in the glass surface is possible after a few months of normal storage. For this reason, applying a protective coating or lamination is recommended for durable optical filter glass from Group 1 (SCHOTT can provide both).

5.6 Solarization effects

Prolonged exposure to intense light sources with high ultraviolet radiation can cause permanent changes (reductions) in the transmissions of optical filter glasses. In glass technology this effect is called “solarization.” It is mainly a function of the intensity and spectral distribution of the radiation. The shorter the wavelength of the radiation, the higher the solarization effect.

The solarization effect manifests itself mainly by a shift of the shortwave-located edge to longer wavelengths and a reduction of the transmission in the pass range. Depending on the spectral distribution, intensity and duration of the irradiation, a saturation effect will set in. If the transmittance curve, resulting from this effect, is acceptable for the application, such a glass can be “aged” prior to use by exposing it to appropriate pre-irradiation. KG heat protection filters for xenon lamps are an important example for such an application.

Since the solarization of an optical filter glass is strongly dependent upon the spectral distribution and intensity of the light source, the duration and the geometrical arrangement of the irradiation, no detailed information can be given on solarization. Optical filter glasses that are prone to higher solarization are identified by the symbol UV in the “Properties” brochure.

Strengthened filter glass with
scratch-resistant coating.

6. Internal quality

The internal quality of optical filter glasses is characterized by the following features.

6.1 Bubbles and inclusions

SCHOTT optical filter glasses are characterized by their particularly small number of bubbles. However, it is not always possible to avoid bubbles in the glass. The description of the content of bubbles and inclusions varies for unpolished glass and polished optical filter components. The reason is that bubble classes for unpolished glasses are defined for a rather large volume of 100 cm^3, while polished optical filter components are often much smaller. Therefore, it is not at all unusual to produce bubble-free components from a block of filter glass with bubble class 3.

6.1.1 Bubbles and inclusions in matte optical filter glass plates

The bubble content of an optical filter glass is characterized by stating the total cross-sectional area of the bubbles in mm^2 relative to 100 cm^3 of optical filter glass volume, calculated from the sum of the cross-sectional areas of the individual bubbles detected.

Inclusions in optical filter glass, such as small stones or crystals, are treated as bubbles of the same cross-sectional area. Only bubbles and inclusions that are larger than 0.03 mm in diameter are covered in the assessment. The bubble classes are shown in **table 6.1**:

Bubble class of matte plates	Total cross-section of all bubbles/inclusion ≥0.03 mm in mm^2 per 100 cm^3 of glass volume	
B0		≤0.03
B1	>0.03	≤0.10
B2	>0.10	≤0.25
B3	>0.25	≤0.50

Table 6.1
The bubble classes of matte colored optical filter glass plates.

6.1.2 Bubbles and inclusions in polished optical filters

If the transmittance is high enough, polished optical filter glass components can easily be inspected. Therefore, any desired specification of internal quality can be produced.

The internal quality of optical filter glass components must be specified in accordance with the standard ISO 10110 Part 3. Should no specifications be made by the customer upon ordering, the permissible amount of bubbles and inclusions is 1/5 x 0,4 for all sizes of polished filters. (This complies with the regulations of ISO 10110 part 11 at a standard size of the filter of over 30 mm and up to 100 mm.) This specification is valid only if the transmittance of the filter is high enough.

For filters that are too dark for inspection, only surface defects can be inspected, and the minimum requirements of ISO 10110 part 11 apply for the surface imperfections. Tighter specifications are possible on request.

6.2 Striae

Striae are locally limited areas that can be detected due to their refractive index which differs from the base glass. Classes of striae are defined in ISO 10110 Part 4. The shadowgraph method is used to determine the striae quality grade.

Striae evaluation is dependent on the transparency of the optical filter glass. Thus, a specification for striae is applicable only for polished optical filter components.

6.3 Homogeneity of refractive index

The variation of the refractive index within an optical filter glass is a measure of its optical homogeneity. The better the homogeneity, the smaller the variation in refractive index. Insofar as the transparency of the optical filter glass type allows, indirect homogeneity measurements can be performed for polished optical filter glass components by measuring the wavefront error.

7. Further processing of optical filter glass

SCHOTT offers high-performance, custom-designed, unpolished, polished, and coated optical filters to meet your application demands.

7.1 Polished optical filters

Our polished optical filter components are characterized by their special quality of the material, their accuracy of shape, excellent surface quality and outstanding optical performance. The international standard ISO 10110 defines the quality aspects of an optical component.

Optical filters are supplied in the form of polished plates or discs with machined edges. Our polishing quality ranges from P2 up to P4 (according to ISO 10110 Part 8).

The optical function of a filter component is not only the correct spectral transmittance. Especially for imaging optics, the wavefront may not be distorted. Wavefront distortion is a function of surface shape, parallelism and the homogeneity of the glass. Thus, for applications with high optical requirements, it is advisable to specify the permissible wavefront deformation instead of specifying the shape, parallelism and homogeneity separately with unobtainable tolerances. The wavefront deformation of all our optical filter glasses can be measured, even for glasses with transmittance in the near infrared range.

In order to improve the surface hardness and strength of an optical filter component; a thermal toughening (strengthening, hardening) can be applied (see section 4.3).

Considering the variety of possible applications, the range of optical filter glasses is not limited to certain standard sizes and thicknesses, rather they can be produced to specification, subject to each individual glass type's maximum possible dimensions and thicknesses.

Special chamfers and edges are available upon request.

7.2 Coatings

Polished filters can be supplied with additional optical coatings to improve the optical properties or add new functions to the optical filter component.

Such coatings include:
- Anti-reflection coatings
- Protective coatings
- Multi-layer interference coatings
- Mirror coatings
- Electrically conductive coatings
- Demisting coatings (anti-fog/hydrophilic)

For more detailed information on coating capabilities, please refer to our website www.schott.com/advanced_optics/optical-filter-glass or contact a sales representative.

BG filters are ideally suited for use as NIR cut filters.

8. Applications

This chapter gives a short overview of some applications which utilize optical filter glasses.

Depending on the spectral requirements, a longpass filter can be designed to pass or block wavelengths inside the radiation management system. For example, interference bandpass filters block shorter wavelengths.

RG filters (such as RG780, RG830, and RG850) which appear black to the eye serve for the **separation of visible and infrared radiation**. While they almost totally absorb visible radiation, the highest possible levels of the longer wavelength infrared radiation can pass through the optical filter.

There are many **sensor** applications in the near infrared region, where undesirable visible radiation can distort measurements or even make them impossible to use and must therefore be eliminated totally.

An additional area in which RG filter glasses are used is in infrared lighting technology. Lamps equipped with these optical filters only emit infrared radiation and appear black to the observer, even during operation, because the visible radiation is absorbed effectively. Therefore, these lamps are especially suited for use in darkness and do not emit any disturbing radiation or become visible. These optical filters, combined with infrared sensitive cameras, allow **surveillance systems (object protection)** to operate unnoticed.

Ultraviolet transmitting optical filter glasses from the **UG group** are often used in UV lighting situations. In this area, the simultaneous presence of visible radiation is frequently undesirable.

Especially in the **excitation of materials with ultraviolet radiation** for producing visible luminescence, the optical filter must guarantee sufficiently strong suppression of the visible radiation from the radiation source. In UG5 and UG11, for example, this can be achieved by selecting an appropriate filter thickness. UG5 optical filter glass is especially well suited for the 254 nm line of a low pressure mercury lamp, while UG11 is frequently used for selecting the 365 nm mercury line.

Neutral density glasses with the designation NG offer, as their name implies, rather constant transmission over a broad spectral range, especially in the visible range. The degree of desired filtering can be regulated by using different NG filter types and thicknesses in a specific type of filter. Their use is indicated when the user requires **defined attenuation of the intensity of radiation sources over a broad spectral range**.

The various optical filter glasses from the **BG group** are used to **correct the sensitivity of silicon receivers**, with their maximum sensitivity in the range between approx. 800 nm and 900 nm, depending on the type of silicone sensors. The increase in detection sensitivity from the blue to the near infrared in detection results in an over evaluation of the longwave (red) area. By selecting the appropriate BG glasses, this can be compensated to a certain extent.

The high-performance optical filter glasses BG39, BG50/55, BG60/61/62 and S-8612 are suited for use in electronic cameras.

A special application for a **bandpass filter** is covered by the NVIS-compatible glasses. These optical glasses have a certain color with a small radius of tolerance. In addition, their optical density is high for wavelengths that are usually enhanced by night vision equipment.

Because of the distinct color of our optical filter glasses, these glasses can also be used as optical filters in photography.

Longpass filters that are IR transmittant.

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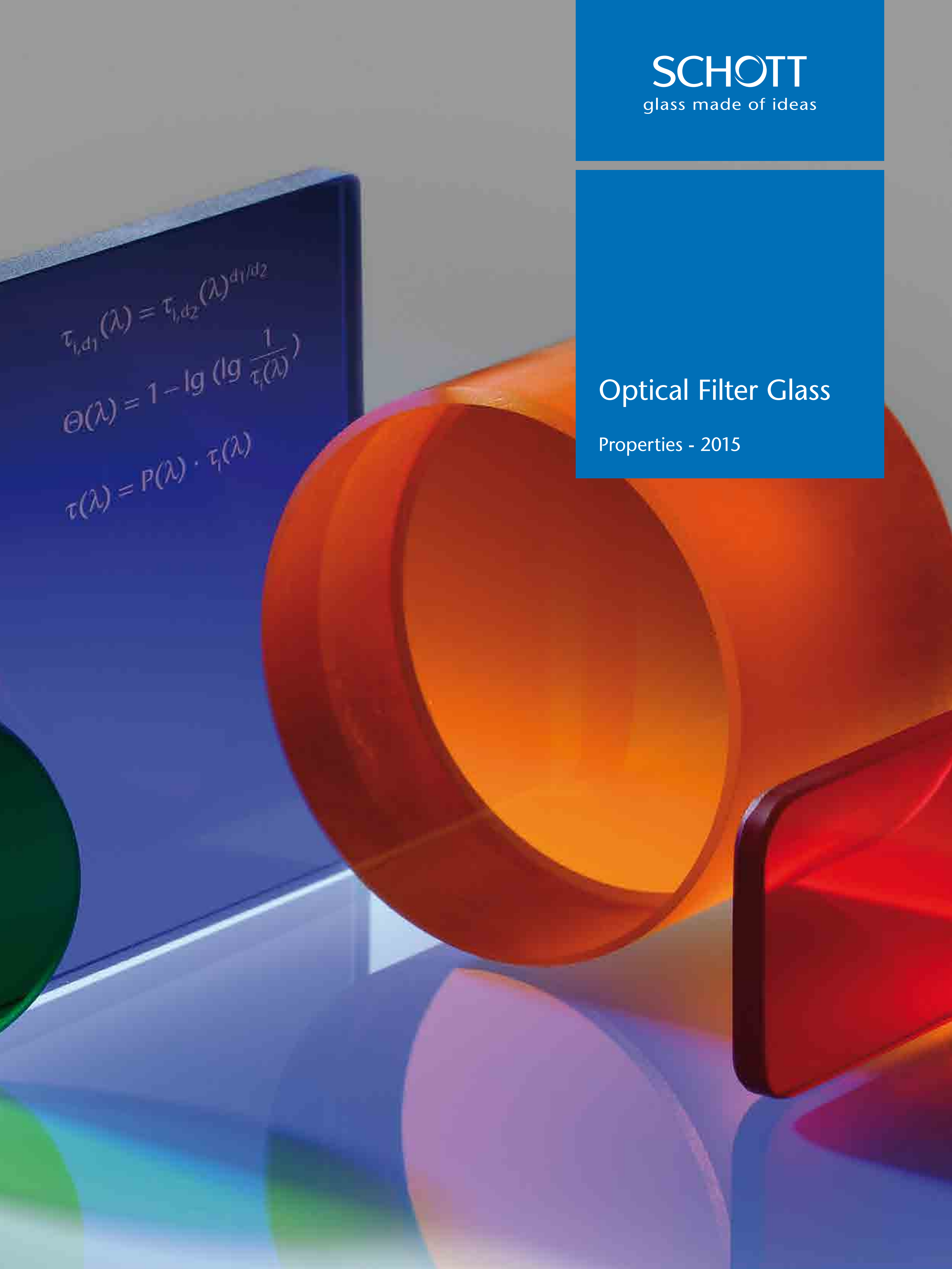
SCHOTT
glass made of ideas



Optical Filter Glass

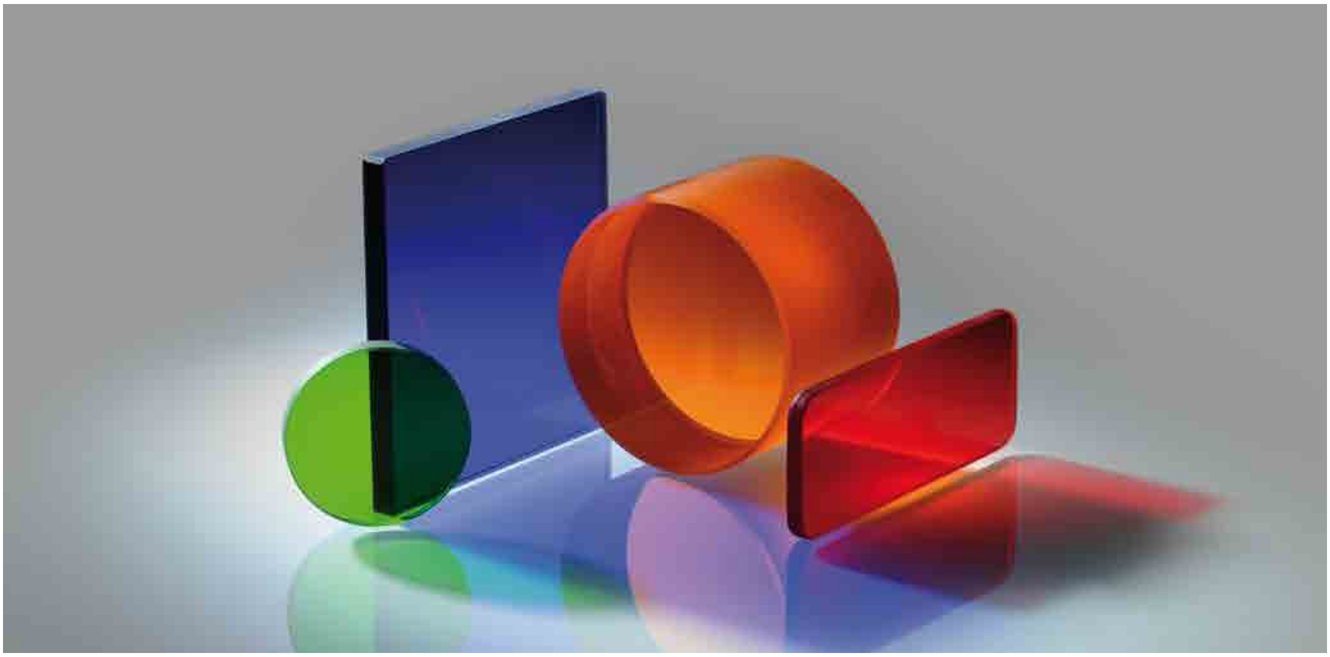
Properties - 2015

SCHOTT is an international technology group with more than 125 years of experience in the areas of specialty glasses and materials and advanced technologies. With our high-quality products and intelligent solutions, we contribute to our customers' success and make SCHOTT part of everyone's life.

SCHOTT Advanced Optics, with its deep technological expertise, is a valuable partner for its customers in developing products and customized solutions for applications in optics, lithography, astronomy, opto-electronics, life sciences, and research. With a product portfolio of more than 120 optical glasses, special materials and components, we master the value chain: from customized glass development to high-precision optical product finishing and metrology.

SCHOTT: Your Partner for Excellence in Optics.

Title
Various optical filter glasses that meet individual requirements and enable customized solutions.



Contents

1. Optical filter glass: product line

The color filter glass product line comprises of more than 58 optical filter glass types.

New optical filters such as BG60, BG61, and BG62 have been developed recently. These glasses are optimized IR cut-filters for difficult environments because of the outstanding resistance against humidity.

Our current product line consists of the following optical filter glass types:

Table 1.1
Product line

UG1	BG3	VG9	GG395	OG515	RG9	NG1	N-WG280	KG1	S8022
UG5	BG7		GG400	OG530	RG610	NG3	N-WG295	KG2	S8023
UG11	BG18		GG420	OG550	RG630	NG4	N-WG305	KG3	
	BG25		GG435	OG570	RG645	NG5	N-WG320	KG5	
	BG36		GG455	OG590	RG665	NG9			
	BG38		GG475		RG695	NG11			
	BG39		GG495		RG715				
	BG40				RG780				
	BG42				RG830				
	BG50				RG850				
	BG55				RG1000				
	BG60								
	BG61								
	BG62								
	S8612								

The following optical filter glass types will be manufactured if there is sufficiently large demand. We will gladly discuss minimum purchase quantities and costs with you.

Table 1.2
Optical filter glasses produced upon request

BG 4	VG 6	GG 385	NG 10	WG 225	KG 4	FG 3
BG 12	VG 14		NG 12			FG 13
BG 20						
BG 23						
BG 24A						
BG 26						
BG 28						
BG 34						

All data listed in this brochure without tolerances are to be understood as reference values. Only those values listed in chapter 2 of this "Properties" brochure under "Limit values of τ_i," "Tolerances of NVIS filters," "Tolerance ranges of τ_i," and "Tolerances for longpass filters" are guaranteed values. The graphically depicted internal transmittance curves serve as an initial overview to assist you in finding the most suitable filter type for your application.

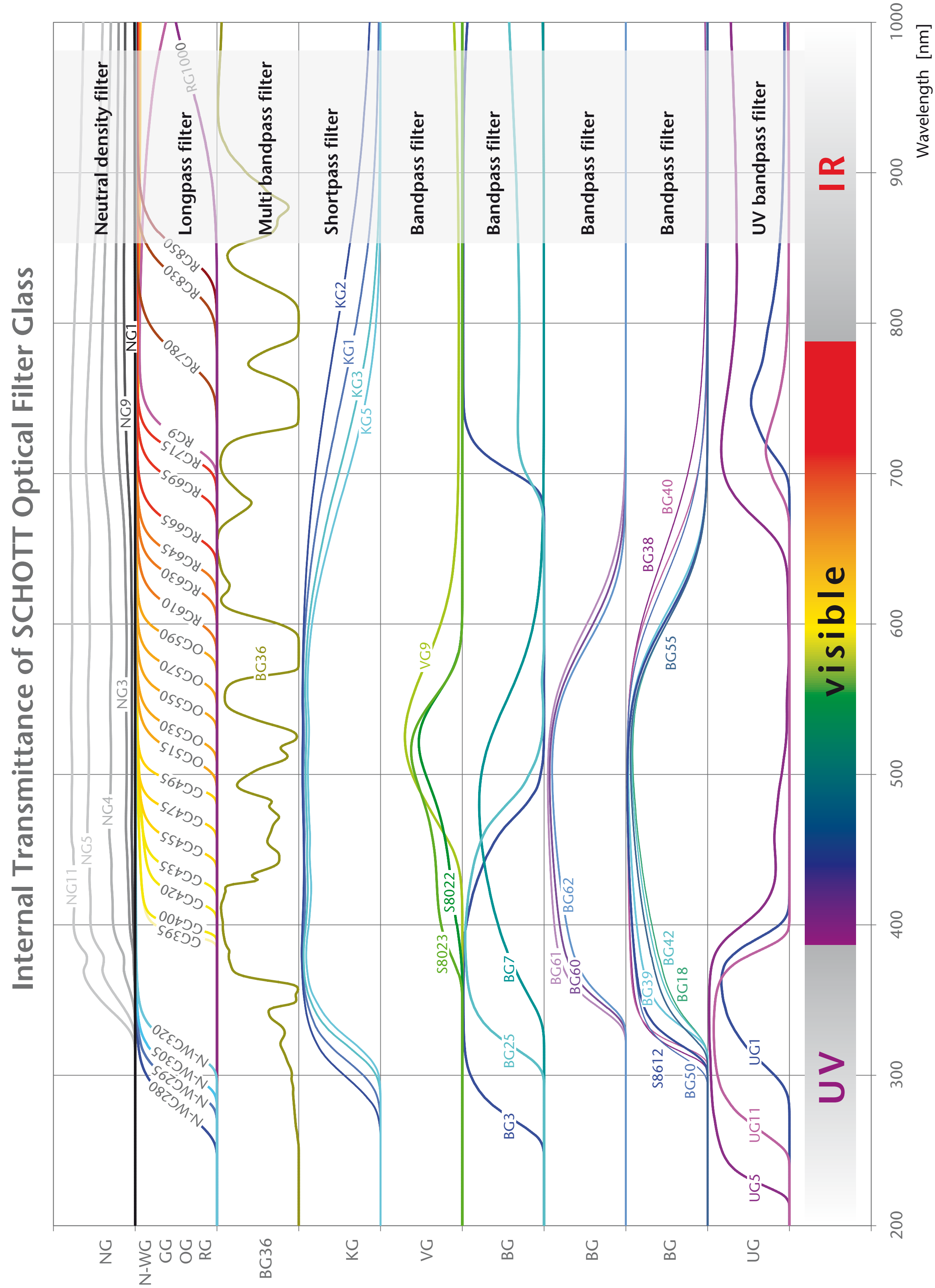


Fig. 1.1
SCHOTT optical filter glass portfolio: The transmittance of all optical filters is depicted in 9 groups, where the ordinate is in linear scale.

2. Optical filter glass: guaranteed values

Limit values of τ_i for shortpass and bandpass filters

Filter glass type	Thickness [mm]	τ_i (λ[nm])	τ_i (λ[nm])	τ_i (λ[nm])	τ_i (λ[nm])	τ_i (λ[nm])	τ_i (λ[nm])	τ_i (λ[nm])	τ_i (λ[nm])
UG1	1	≥ 0.80(365)	≤ 0.10(405)	≤ 0.06(694)	≤ 0.53(750)				
UG5	1	≥ 0.80(254)	≥ 0.94(308)	≤ 0.50(405)	≤ 0.05(546)	≤ 0.05(633)	≤ 0.85(725)		
UG11	1	≥ 0.06(254)	≥ 0.90(334)	≤ 0.001(405)	≤ 0.26(694)	≤ 0.32(725)			
BG3	1	≥ 0.94(365)	≤ $5 \cdot 10^{-5}$ (633)						
BG7	1	≥ 0.25(365)	≥ 0.78(488)	≤ 0.08(633)					
BG18	1	≥ 0.30(350)	≥ 0.65(405)	≥ 0.88(514)	≤ 0.25(633)	≤ 0.03(694)	≤ $5 \cdot 10^{-4}$ (1060)		
BG25	1	≤ 0.80(334)	≥ 0.93(405)	≤ 0.39(488)	≤ 0.36(725)				
BG38	1	≥ 0.80(350)	≥ 0.93(405)	≥ 0.95(514)	≤ 0.67(633)	≤ 0.32(694)	≤ 0.06(1060)		
BG39	1	≥ 0.60(350)	≥ 0.85(405)	≥ 0.93(514)	≤ 0.30(633)	≤ 0.03(694)	≤ 0.001(1060)		
S8612	1	≥ 0.96(500)	≥ 0.48(600)	≤ 0.02(700)					
BG40	1	≥ 0.80(350)	≥ 0.93(405)	≥ 0.97(514)	≤ 0.57(633)	≤ 0.16(694)	≤ 0.02(1060)		
BG42	1	≥ 0.40(350)	≥ 0.65(405)	≥ 0.88(514)	≤ 0.27(633)	≤ 0.03(694)	≤ 0.002(1060)		
BG50	1	≥ 0.96(500)	≥ 0.68(600)	≥ 0.13(700)					
BG55	1	≥ 0.76(405)	≥ 0.93(514)	≥ 0.18(633)	≤ 0.016(694)	≤ 0.0005(1060)			
BG60	1	≥ 0.78(405)	≥ 0.91(514)	≥ 0.10(633)	≤ 0.010(694)	≤ 0.0015(1060)			
BG61	1	≥ 0.84(405)	≥ 0.93(514)	≥ 0.18(633)	≤ 0.030(694)	≤ 0.008(1060)			
BG62	1	≥ 0.71(405)	≥ 0.88(514)	≥ 0.08(633)	≤ 0.005(694)	≤ 0.0005(1060)			
VG9	1	≤ 0.21(450)	≥ 0.67(514)	≤ 0.15(633)	≤ 0.07(725)	≤ 0.18(1060)			
RG9	3	≤ 0.45(720)	≥ 0.92(800)	≤ 0.40(1060)					
KG1	2	≥ 0.89(365)	≥ 0.92(500)	≥ 0.88(600)	≤ 0.68(700)	≤ 0.33(800)	≤ 0.10(900)	≤ 0.02(1060)	≤ 0.06(2200)
KG2	2	≥ 0.93(365)	≥ 0.94(500)	≥ 0.92(600)	≤ 0.83(700)	≤ 0.55(800)	≤ 0.28(900)	≤ 0.12(1060)	≤ 0.20(2200)
KG3	2	≥ 0.86(365)	≥ 0.88(500)	≥ 0.83(600)	≤ 0.55(700)	≤ 0.14(800)	≤ 0.03(900)	≤ 0.001(1060)	≤ 0.01(2200)
KG5	2	≥ 0.80(365)	≥ 0.86(500)	≥ 0.80(600)	≤ 0.43(700)	≤ 0.09(800)	≤ 0.008(900)	≤ $1 \cdot 10^{-4}$ (1060)	≤ 0.001(2200)

Table 2.1: Spectral values guaranteed for shortpass and bandpass filters

Tolerances for NVIS filters

Filter glass type	Thickness [mm]	Photopic transmittance [%]		NVIS color according to MIL-STD-3009
		2100K	1500K	
S8022	2	13.5 ± 1.5	9.0 ± 1.5	Green A
S8023	3	15.0 ± 1.5	10.0 ± 1.5	Green A

Table 2.2: Values guaranteed for NVIS filters

Tolerance ranges of τ_i for neutral density filters

Filter glass type	Thickness [mm]	τ_i (λ[nm])	τ_i (λ[nm])	τ_i (λ[nm])
NG1	1	$< 1 \cdot 10^{-4}$ (546)		
NG3	1	0.06 ± 0.02(405)	0.10 ± 0.02(546)	0.17 ± 0.03(694)
NG4	1	0.27 ± 0.03(405)	0.31 ± 0.03(546)	0.39 ± 0.04(694)
NG5	1	0.56 ± 0.03(405)	0.57 ± 0.03(546)	0.62 ± 0.03(694)
NG9	1	0.025 ± 0.01(405)	0.04 ± 0.02(546)	0.08 ± 0.02(694)
NG11	1	0.76 ± 0.02(405)	0.77 ± 0.02(546)	0.79 ± 0.02(694)

Table 2.3: Spectral values guaranteed for neutral density filters

Tolerances and limit values for longpass filters

Filter glass type	Thickness [mm]	λ_c ($\tau_i = 0.50$)[nm]	λ_s ($\tau_{is} \leq 1 \cdot 10^{-5}$)[nm]	λ_{p1} (τ_{ip1})[nm]	λ_{p2} (τ_{ip2})[nm]
N-WG280	2	280 ± 6	230	380(0.99)	
N-WG295	2	295 ± 6	250	400(0.99)	
N-WG305	2	305 ± 6	260	420(0.99)	
N-WG320	2	320 ± 6	280	470(0.99)	
GG395	3	395 ± 6	340	480(0.92)	
GG400	3	400 ± 6	340	480(0.93)	
GG420	3	420 ± 6	360	530(0.93)	
GG435	3	435 ± 6	370	520(0.92)	
GG455	3	455 ± 6	390	530(0.92)	
GG475	3	475 ± 6	410	550(0.92)	
GG495	3	495 ± 6	430	560(0.92)	
OG515	3	515 ± 6	440	580(0.93)	
OG530	3	530 ± 6	460	600(0.93)	
OG550	3	550 ± 6	480	620(0.93)	
OG570	3	570 ± 6	500	640(0.93)	
OG590	3	590 ± 6	510	660(0.93)	
RG610	3	610 ± 6	530	690(0.94)	
RG630	3	630 ± 6	540	710(0.94)	
RG645	3	645 ± 6	560	720(0.94)	
RG665	3	665 ± 6	580	750(0.96)	
RG695	3	695 ± 6	610	780(0.96)	
RG715	3	715 ± 9	620	810(0.96)	
RG780	3	780 ± 9	610	900(0.97)	
RG830	3	830 ± 9	670	950(0.97)	
RG850	3	850 ± 9	700	950(0.90)	1200(0.97)
RG1000	3	1000 ± 6	730	1300(0.90)	

Table 2.4: Spectral values guaranteed for longpass filters

3. Optical filter glass: reference values

Filter glass type	Density ρ [g/cm^3]	Reflection factor P for λ = 587.6 nm	Refractive index n for λ = 587.6 nm	Bubble class	Stain resistance FR	Acid resistance SR	Alkali resistance AR	Transformation temperature Tg [°C]	Thermal expansion $\alpha_{-30/+70°C}$ [10^{-6}/K]	Thermal expansion $\alpha_{20/300°C}$ [10^{-6}/K]	Temperature coefficient T_K [nm/°C]	Notes*
UG1	2.77	0.91	1.54	1	0	1.0	1.0	603	7.9	8.9		
UG5	2.85	0.91	1.54	2	0	3.0	2.0	462	8.1	9.4		
UG11	2.92	0.91	1.56	2	0	3.0	2.2	545	7.8	9.0		
BG3	2.56	0.92	1.51	1	0	1.0	1.0	478	8.8	10.2		
BG7	2.61	0.92	1.52	1	0	1.0	1.0	468	8.5	9.9		
BG18	2.68	0.91	1.54	2	0	2.0	2.0	482	7.4	8.8		
BG25	2.56	0.92	1.51	1	0	1.0	1.0	487	8.7	10.1		
BG36	3.59	0.88	1.69	3	1	52.2	1.2	657	6.1	7.2		
BG38	2.66	0.92	1.53	2	0	2.0	2.0	482	7.5	8.9		
BG39	2.74	0.91	1.54	2	0	5.1	3.0	322	11.6	13.1**		
S8612	2.68	0.91	1.54	1	0	3.0	3.0	404		9.5		
BG40	2.74	0.92	1.53	2	0	5.1	3.0	313	11.9	13.7**		
BG42	2.69	0.91	1.54	2	0	2.0	2.0	475	7.3	8.7		
BG50	2.61	0.915	1.53	1	0	2.0	2.0	452	7.3	9.0		
BG55	2.64	0.913	1.54	2	0	2.0	2.0	453	7.2	9.1		
BG60	2.83	0.914	1.53	2	1	52.3	3.3	411	–	13.9	–	
BG61	2.81	0.914	1.53	2	1	52.3	3.3	402	11.9	13.9	–	
BG62	2.85	0.914	1.54	2	1	52.3	3.3	410	–	13.6	–	
S8022	2.77	0.91	1.56	1	0	4.0	3.0	453	7.8	8.9		
S8023	2.75	0.91	1.54	1	0	4.0	3.0	444		9.7**		
VG9	2.87	0.91	1.55	1	0	1.0	1.0	462	9.2	10.6		
GG395	2.55	0.92	1.52	3	0	1.0	1.0	538	7.8	9.0	0.07	
GG400	2.55	0.92	1.52	3	0	1.0	1.0	537	7.9	9.1	0.07	
GG420	2.55	0.92	1.52	3	0	1.0	1.0	535	7.8	9.0	0.07	
GG435	2.55	0.92	1.52	3	0	1.0	1.0	537	7.8	9.1	0.08	
GG455	2.56	0.92	1.52	3	0	1.0	1.0	529	8.2	9.5	0.09	
GG475	2.56	0.92	1.52	3	0	1.0	1.0	531	8.2	9.4	0.09	
GG495	2.56	0.92	1.52	3	0	1.0	1.0	535	8.1	9.4	0.10	
OG515	2.56	0.92	1.51	3	0	1.0	1.0	509	7.9	9.0	0.11	
OG530	2.56	0.92	1.51	3	0	1.0	1.0	506	7.9	9.0	0.11	
OG550	2.56	0.92	1.51	3	0	1.0	1.0	507	7.9	9.0	0.12	
OG570	2.56	0.92	1.51	3	0	1.0	1.0	510	7.9	9.0	0.12	
OG590	2.56	0.92	1.51	3	0	1.0	1.0	506	7.9	9.0	0.13	
RG9	2.58	0.92	1.52	3	0	1.0	1.0	519	7.9	9.0	0.06	
RG610	2.65	0.92	1.52	3	0	1.0	1.0	520	8.0	9.2	0.14	
RG630	2.65	0.92	1.52	3	0	1.0	1.0	527	8.0	9.2	0.14	

Table 3: Physical and chemical properties (for reference only)

* Long-term changes and solarization properties (see sections 5.5 and 5.6 of the "Descriptions" brochure)
** $\alpha_{20/200°C}$

Filter glass type	Density ρ [g/cm^3]	Reflection factor P for λ = 587.6 nm	Refractive index n for λ = 587.6 nm	Bubble class	Stain resistance FR	Acid resistance SR	Alkali resistance AR	Transformation temperature Tg [°C]	Thermal expansion $\alpha_{-30/+70°C}$ [10^{-6}/K]	Thermal expansion $\alpha_{20/300°C}$ [10^{-6}/K]	Temperature coefficient T_K [nm/°C]	Notes*
RG645	2.65	0.92	1.52	3	0	1.0	1.0	519	8.0	9.2	0.16	
RG665	2.77	0.91	1.54	3	0	1.0	1.0	527	8.1	9.4	0.17	
RG695	2.76	0.91	1.54	3	0	1.0	1.0	532	8.1	9.4	0.18	
RG715	2.76	0.91	1.53	3	0	1.0	1.0	532	8.1	9.4	0.18	
RG780	2.94	0.91	1.56	3	5	53.4	1.3	552	9.5	10.5	0.22	
RG830	2.94	0.91	1.56	3	5	53.4	1.3	554	9.5	10.5	0.23	
RG850	2.93	0.91	1.56	3	5	53.4	1.3	554	9.5	10.5	0.24	
RG1000	2.73	0.91	1.54	3	0	1.0	1.0	476	9.0	10.3	0.41	
NG1	2.47	0.92	1.52	2	1	2.2	1.0	471	6.6	7.2		
NG3	2.44	0.92	1.51	2	1	2.2	1.0	462	6.5	7.3		
NG4	2.43	0.92	1.51	2	1	2.2	1.0	483	6.7	7.2		
NG5	2.43	0.92	1.50	2	1	3.2	2.0	474	6.6	7.3		
NG9	2.45	0.92	1.51	2	1	3.2	2.0	470	6.4	7.2		
NG11	2.42	0.92	1.50	2	1	3.4	2.0	481	6.9	7.5		
N-WG280	2.51	0.92	1.52	1	0	1.0	2.0	558	7.1	8.4	0.06	
N-WG295	2.51	0.92	1.52	1	0	1.0	2.0	565	7.2	8.4	0.06	
N-WG305	2.51	0.92	1.52	1	0	1.0	2.0	562	7.1	8.4	0.06	
N-WG320	2.51	0.92	1.52	1	0	1.0	2.0	563	7.1	8.4	0.06	
KG1	2.53	0.92	1.52	3	0	2.0	3.0	599	5.3	6.1		
KG2	2.52	0.92	1.51	3	0	2.0	3.0	605	5.4	6.3		
KG3	2.52	0.92	1.51	3	0	2.0	4.0	581	5.3	6.1		
KG5	2.53	0.92	1.51	3	0	3.0	4.0	565	5.4	6.2		

Table 3: Physical and chemical properties (for reference only) (continued)

* Long-term changes and solarization properties (see sections 5.5 and 5.6 of the "Descriptions" brochure)

4. Internal transmittance graphs

The internal transmittance curves are to be understood to be typical curves for first information only. Additional information is contained in the data sheets. The information relating to filter color, which is more or less subjective, is based on the reference thickness listed for the optical filter glasses. The determination was made in natural daylight. The data sheets contain additional information regarding colorimetric evaluations.

UV bandpass filter

UG1, UG5, UG11

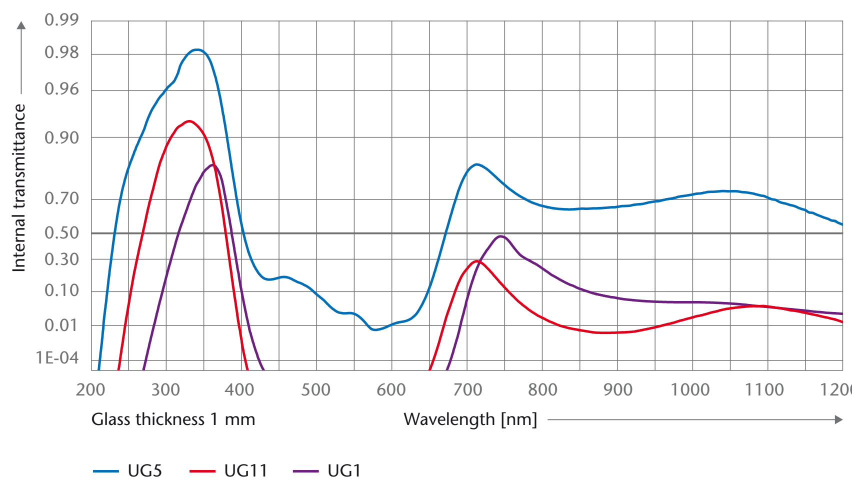


Fig. 4.1

Bandpass filter

BG3, BG25, RG9

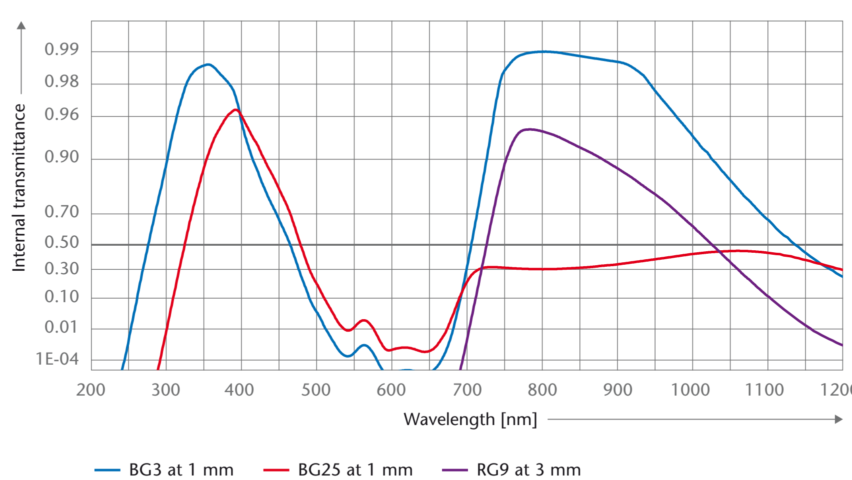


Fig. 4.2

Bandpass filter

BG7, VG9

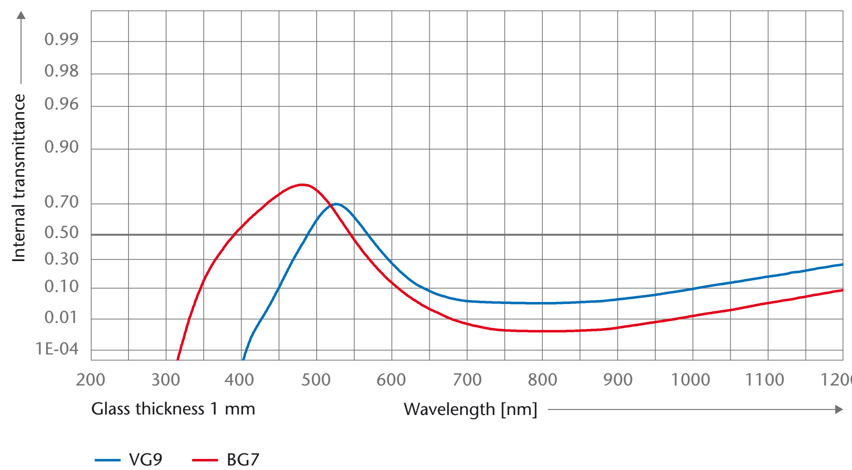


Fig. 4.3

Bandpass filter

BG18, BG38, BG40, BG42, BG50

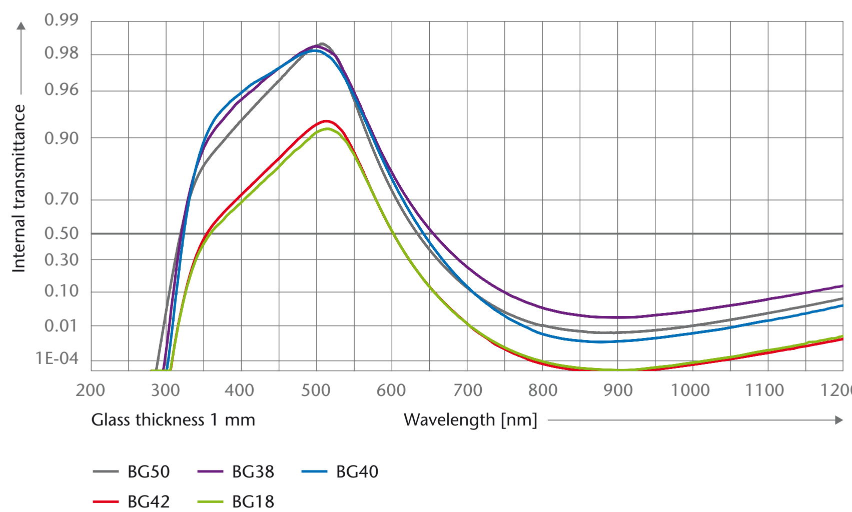


Fig. 4.4

Bandpass filter

BG60, BG61, BG62

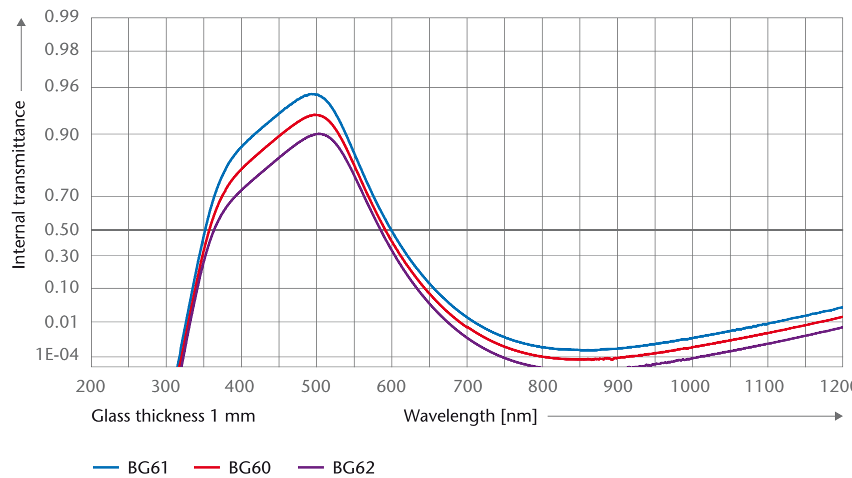


Fig. 4.5

Bandpass filter

S8612, BG39, BG55

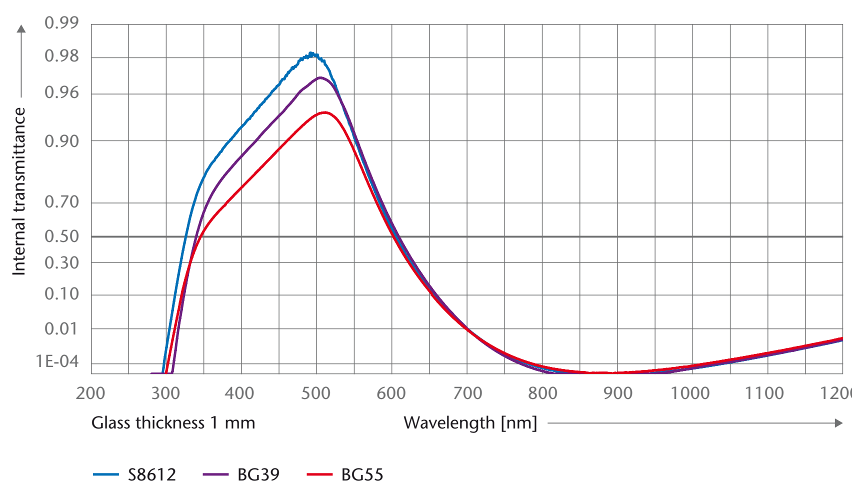


Fig. 4.6

Bandpass filter NVIS Green A

S8022, S8023

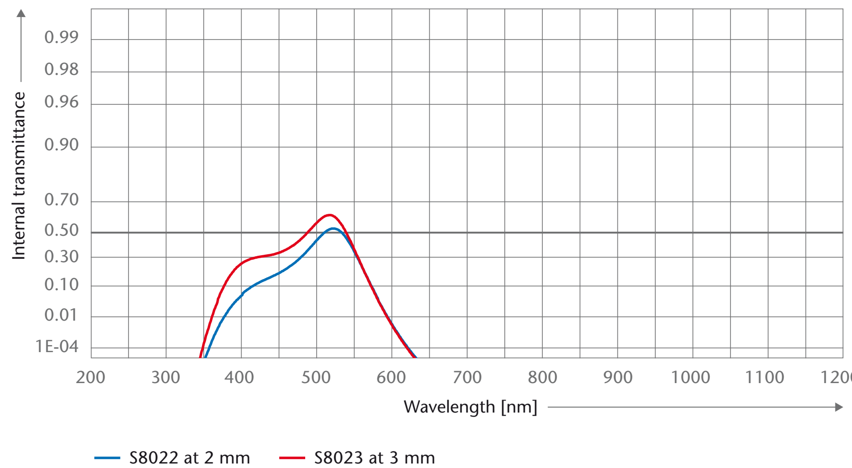
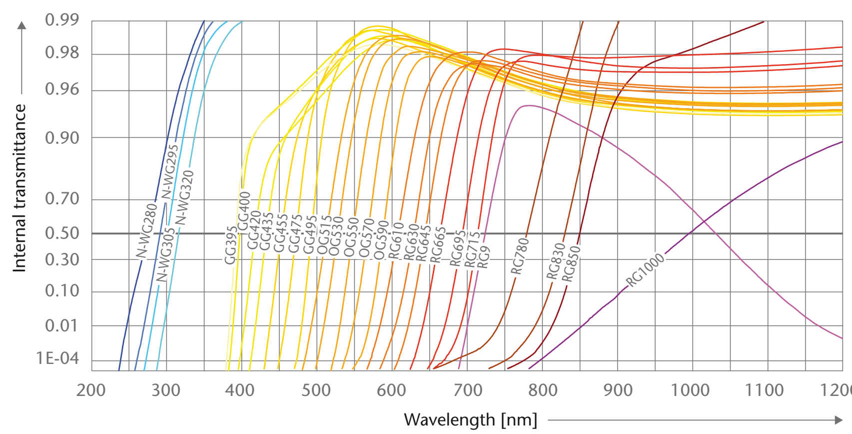


Fig. 4.7

Longpass filter

N-WG280, N-WG295, N-WG305, N-WG320
GG395, GG400, GG420, GG435, GG455, GG475, GG495
OG515, OG530, OG550, OG570, OG590
RG9, RG610, RG630, RG645, RG665, RG695, RG715, RG780, RG830, RG850, RG1000



Glass thickness 2 mm (N-WG types)
Glass thickness 3 mm (all other types)

Fig. 4.8

Multiband filter

BG36

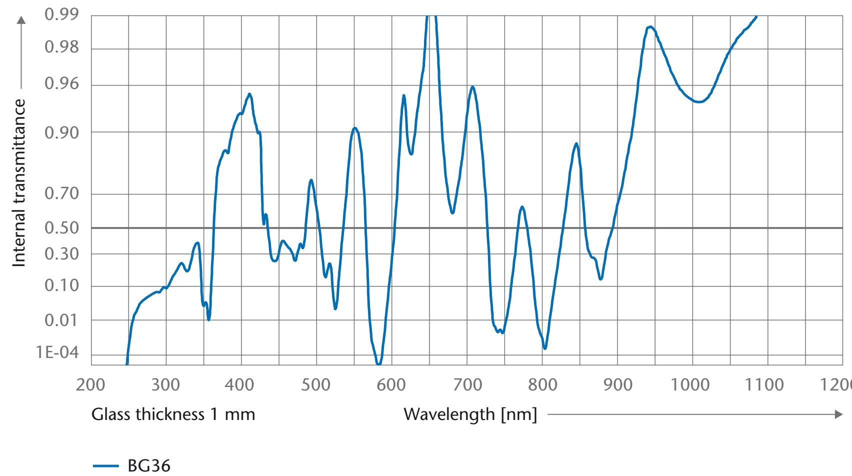


Fig. 4.9

Shortpass filter

KG1, KG2, KG3, KG5

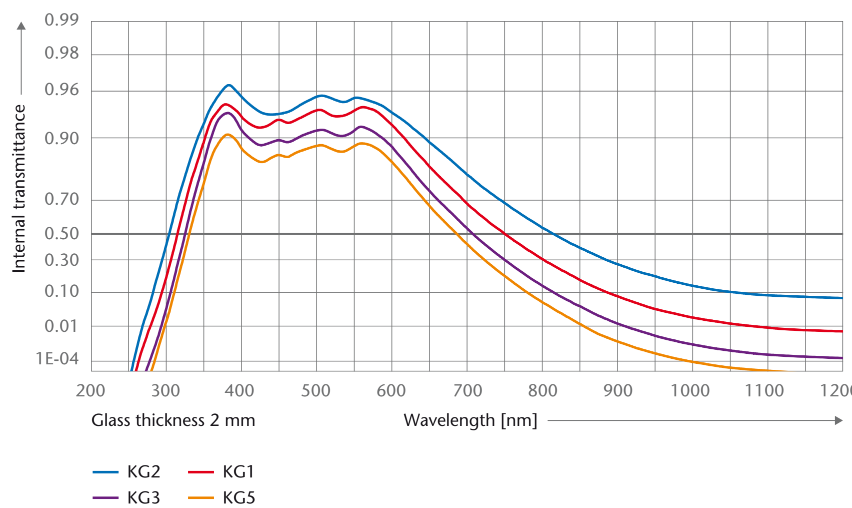


Fig. 4.10

Neutral density filter

NG1, NG3, NG4, NG5, NG9, NG11

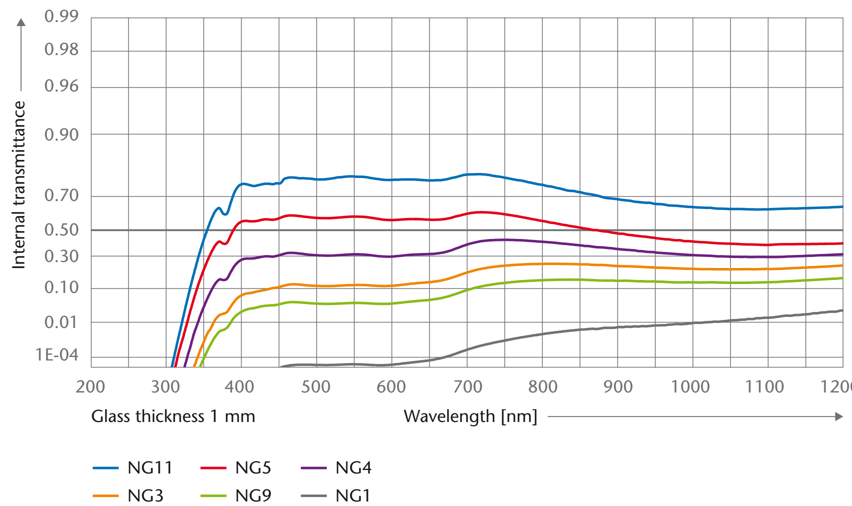
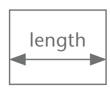
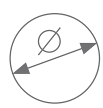


Fig. 4.11

5. Tolerances for polished filters

Dimensions

The minimum thickness and the tolerances do not apply for all possible combinations of dimensions and glass types. Some sensitive glasses may require greater thickness or weaker tolerances.

	Edge length [mm]	Minimum thickness [mm] precision	Minimum thickness [mm] standard	Chamfer [mm]
Rectangular shape 	≤ 200 ± 0.1	1.0 ± 0.1	1.5 ± 0.2	0.1 ~ 0.5
	≤ 120 ± 0.1	0.4 ± 0.1	1.0 ± 0.1	
	≤ 100 ± 0.1	0.4 ± 0.05	0.7 ± 0.1	
	≤ 50 ± 0.1	0.25 ± 0.03	0.5 ± 0.05	
	Diameter [mm]	**Minimum thickness [mm] precision**	**Minimum thickness [mm] standard**	**Chamfer [mm]**
Disc shape 	≤ Ø 250 ± 0.1	1.5 ± 0.1	2 ± 0.2	0.1 ~ 0.5
	≤ Ø 200 ± 0.1	0.5 ± 0.05	1.0 ± 0.1	
	≤ Ø 150 ± 0.1	0.4 ± 0.05	0.7 ± 0.1	
	≤ Ø 100 ± 0.1	0.3 ± 0.03	0.5 ± 0.05	
	≤ Ø 50 ± 0.1	0.2 ± 0.03	0.4 ± 0.05	
Other shapes and sizes	Other shapes and sizes are available upon special request. Min Ø 4 mm.			

Polished surfaces

Specifications depend on the geometry (thickness, size, shape, effective area) of the filter.

Surface quality	superior	premium	standard
ISO 10110-7	5/ 3 x 0.16	5/ 3 x 0.16	5/ 3 x 0.63
MIL-PRF-13830 B	20/10	40/20	60/40

Parallelism	≤ 30''	≤ 30''	30'' – 1'

Optical quality

Wavefront error ISO 10110-14	Upon request	Upon request	Upon request

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10391 ENGLISH | Version January 2015

SCHOTT
glass made of ideas

Interference Filters & Special Filters

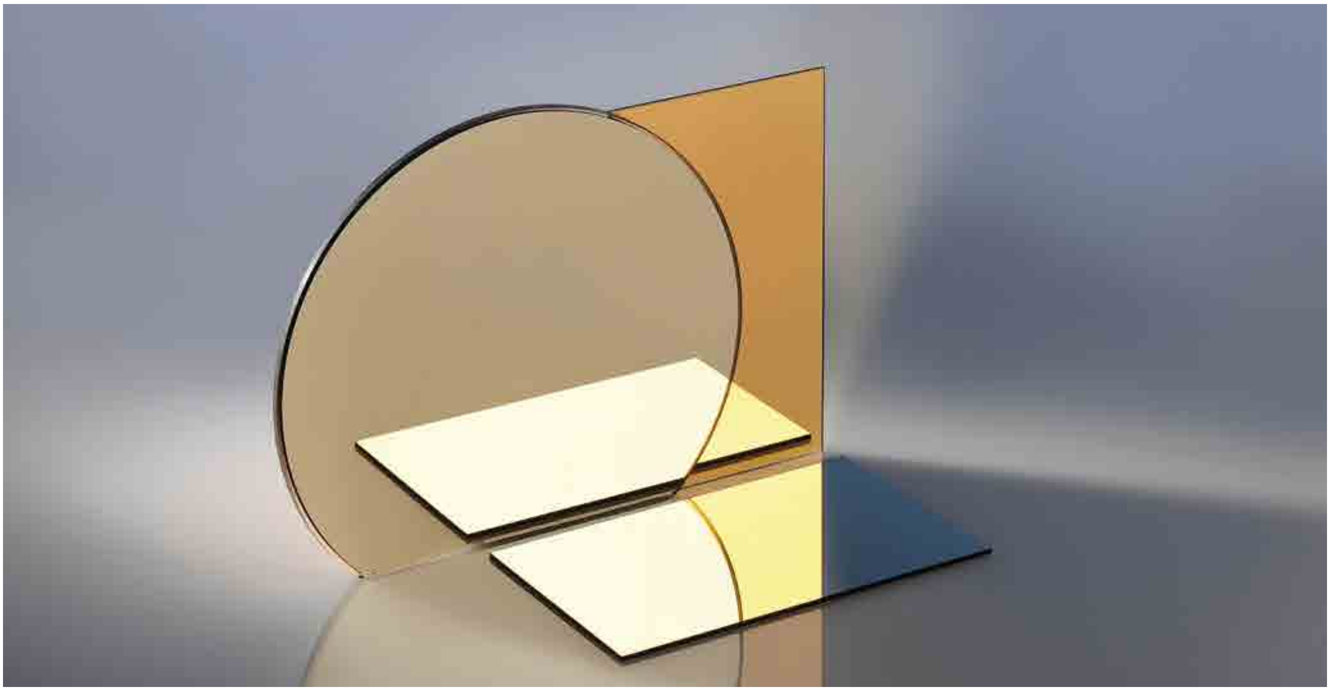
Description - 2015

SCHOTT is an international technology group with more than 125 years of experience in the areas of specialty glasses and materials and advanced technologies. With our high-quality products and intelligent solutions, we contribute to our customers' success and make SCHOTT part of everyone's life.

SCHOTT Advanced Optics, with its deep technological expertise, is a valuable partner for its customers in developing products and customized solutions for applications in optics, lithography, astronomy, opto-electronics, life sciences, and research. With a product portfolio of more than 120 optical glasses, special materials and components, we master the value chain: from customized glass development to high-precision optical product finishing and metrology.

SCHOTT: Your Partner for Excellence in Optics.

Title
Dielectric mirror coatings.



Contents

1. Introduction

1.1 Foreword

Interference filters are used in various industries and enable challenging applications. Leveraging the function of various substrate materials in combination with special coatings, SCHOTT has been developing such filters since 1939.

While advancing its capabilities SCHOTT has continuously expanded its interference and special filter program.

These developments are reflected in this brochure. The content has been updated and new products based on our latest technologies have been added. Thus, SCHOTT's Interference Filters & Special Filters Brochure can be used as a reliable information source for system designers and optical engineers developing solutions for optical applications that meet a wide variety of different market needs.

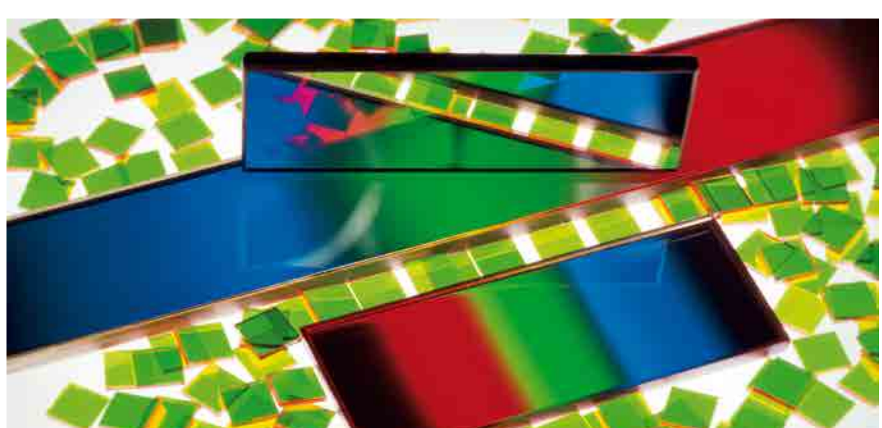
Interference filters and special filters are described in two different brochures. This brochure named "Description" informs about the most important criteria that pertain to the materials and characteristics of the filters. The other brochure named "Properties" covers additional technical information on each filter.

If any information not covered in this brochure is needed, please contact one of our regional sales representatives all over the world. Our experts will consult you and help in finding a solution for your challenge, since we believe the close relationship to our customers is key for successful work.

As we constantly strive to improve our products to your advantage through innovation and new technical developments, we reserve the right to change the optical and non-optical data in our Interference Filters & Special Filters Brochure without prior notice. The new brochures were assembled with the utmost care; however, we assume no liability in the unlikely event that there are content or printing errors.

The release of this brochure replaces all previous publications.

January 2015



VERIL filters showing various colors over length and green interference bandpass filters.

1.2 General information

SCHOTT Advanced Optics offers a wide variety of different interference filters for use in medical technology, analytics, consumer and security applications, whereby most of the offered filters are designed and manufactured according to customers' specifications.

SCHOTT first developed interference filters back in 1939, when Dr. Walter Geffcken, a SCHOTT researcher, filed a patent on "**interference filters**" (DE716153 and DE742463 – German patent office), a metal dielectric and all dielectric thin-film filter. In 1940, another patent was filed by Dr. Geffcken on "**coatings with reduced surface reflections**" (CH223344 – Swiss patent office), an AR coating.

Since then SCHOTT has not only built up extensive know-how and state-of-the-art technologies, but also a global production network capable of applying different coatings.

Interference filters use the interference effect to transmit or reflect certain spectral ranges of electromagnetic radiation by applying numerous thin-film layers to a substrate. This leads to various advantages resulting in an extensive use of interference filters in numerous applications and industries.
The main advantages offered are:

- Filter curves and forms can be designed in nearly all wavelength ranges, i.e. according to customers' specifications
- Steep filter edges, on both filter edges if needed
- Splitting of light power, if needed
- Splitting of polarization state, if needed
- A wide variety of different coatings from AR, conductive and mirror to all kinds of interference filter coatings

This brochure contains introductory information such as the explanation of the filters and environmental aspects (chapter 1) as well as specific information about interference filters. Chapter 2 deals with basic information on ADI- and MDI filters. Chapter 3 describes generally valid definitions and chapter 4 defines various properties such as angular or temperature dependence. Chapter 5 deals with coating processes. Chapters 6 to 8 cover topics like custom-made filters, applications and general comments.

Information is also available on the SCHOTT website:
www.schott.com/advanced_optics/interference-filters

Unless mentioned otherwise, all data shown in this brochure are valid at room temperature of 23 °C.

Upon request, the reference values can be specified more closely and the guaranteed values can be adapted to meet your requirements, if possible.

1.3 Explanation of interference filter types

The interference and special filter portfolio of SCHOTT includes the following types of filters:

- **Longpass interference filters** that only permit longer wavelengths to pass through
- **Shortpass interference filters** that only permit shorter wavelengths to pass through
- **Bandpass interference filters** that only permit a certain wavelength band to pass through
- **Neutral density thin-film filters** with a nearly constant transmission spectrum over the VIS spectrum to lower the light by a certain extent
- **Notch filters** or **bandblock filters** that block a certain wavelength band
- **Beam splitters** that split up a share of the incident light, e.g. 50 %
- **Polarizing beam splitters** that split the 2 polarization states
- **Black chrome coatings** to avoid any reflections
- **AR coatings:** V-coating, broadband, multi-band, hard or scratch-resistant
- **Transparent conductive oxide** is a coating that transmits light and is electrically conductive
- **Linear variable filters** are bandpass filters that shift the center wavelength of the bandpasses over the length of the filter
- **Dielectric (laser) mirrors** reflect light with low absorption (and are thus well suited for use in laser applications)
- **Metallic mirrors** reflect light

1.4 Environmental aspects, hazardous substances, RoHS, ISO, REACh

SCHOTT Advanced Optics produces and distributes special materials and components in accordance with professional standards of our global Environmental, Health and Safety Management to prevent environmental pollution and to conserve natural resources and follows the procedures and philosophy of our global Quality Management System. Purchasing and handling of raw materials, the melting of batches, hot forming and coating is done strictly following established safety procedures and fulfilling requirements on material compliance.

All optical materials in this brochure comply with the requirements of the European Directive 2011/65/EU (RoHS). The optical materials featured in this brochure do not contain any mercury (Hg), chromium VI (CrVI) or the flame retardants PBB and PBDE whatsoever. Some of the optical filter glasses may contain lead or cadmium. They are in compliance with RoHS according to exemption 13b documented in ANNEX III of the directive 2011/65/EU.

In addition, all materials discussed in this brochure comply with the requirements of the European Regulation 2006/1907/EC (REACh: Registration, Evaluation and Authorization of Chemical Substances).

2. Basic information on interference filters

Interference filters leverage (as the name implies) the physical effect of the interference of light waves. This is illustrated in **Fig. 2.1** for the case of constructive and destructive interference.

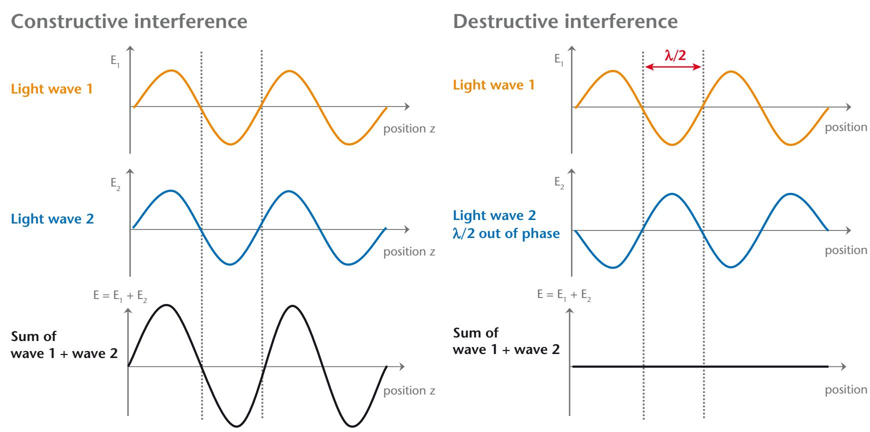


Fig. 2.1
Interference of two light waves for **constructive interference** (left): the two light waves are in phase and add to a superposition of both waves. In contrast, for **destructive interference** (right) one light wave is half a wavelength out of phase leading to light cancelation of the superposition.

As we can see from **Fig. 2.1**, if the two light waves are half a wavelength (or an odd number of half a wavelength) out of phase, then the superposition of both light waves leads to a cancellation of the resulting light if both waves have the same amplitude. It is precisely this light cancellation that is exploited for anti-reflective (AR) coatings, where no light is reflected (back), therefore all light is transmitted. Half a wavelength (λ/2) phase difference can be achieved by using a thin-film layer that is λ/4 thick, see **Fig. 2.2**.

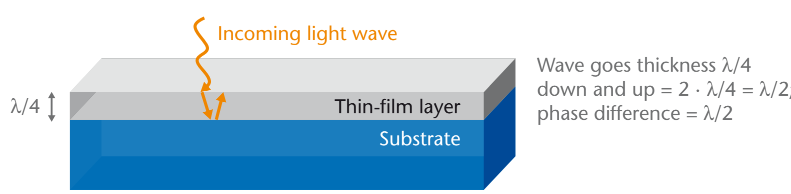


Fig. 2.2
A light wave entering a thin-film layer of thickness λ/4 is reflected backwards at the interface thin-film layer-substrate and thus travels the thickness λ/4 twice resulting in a phase difference of λ/2 (half a wavelength).

As shown in **Fig. 2.2**, a thin-film layer coating of thickness λ/4 generates a phase difference of half a wavelength (λ/2) for the wave traveling backwards. Therefore, no light is reflected back, thus all light must be transmitted. This is illustrated in **Fig. 2.3**.

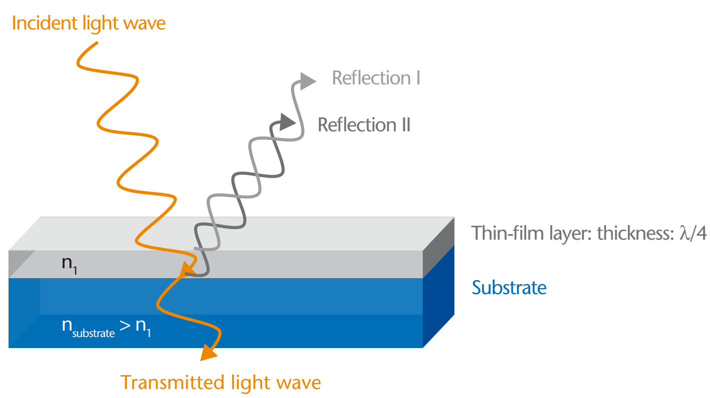


Fig. 2.3
A thin-film layer of thickness λ/4 avoids any back reflection by destructive interference of the two reflected waves resulting in an anti-reflective (AR) coating.

As shown in **Fig. 2.3**, an incident light wave is partly reflected at the interface air-thin-film layer. A second partial reflection occurs at the interface thin-film layer-substrate. Due to the **thin-film thickness of λ/4**, the two light waves referred to as "Reflection I" and "Reflection II" are half a wavelength out of phase. Therefore, both waves interfere destructively and cancel each other out if they have the same amplitude. Thus, no light travels in the backward direction. Nevertheless, all light is transmitted, so this is an **anti-reflective (AR) coating**.

A thin-film layer thickness of half a wavelength (λ/2) results in a phase difference of a wavelength λ and no light will be canceled (see **Fig. 2.1**) in the backward direction. Thus such a **λ/2 thin-film layer** will behave as if it does not exist and part of the light is reflected off the substrate which is sometimes called an "absentee layer."

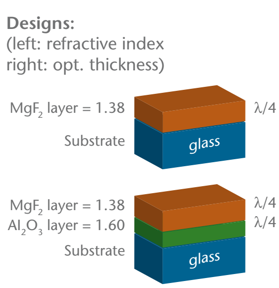
An AR coating must fulfill two conditions: firstly a layer thickness of λ/4. In order to force both reflected light waves to have the same amplitude, the refractive index n_1 of the thin-film layer must fulfill the second condition:

$$n_1 = \sqrt{n_{air} \cdot n_{substrate}}$$

where $\mathbf{n_{air}}$ is the refractive index of the surrounding air and $\mathbf{n_{substrate}}$ is the refractive index of the glass substrate.

Since the thickness "d" of an AR coating is defined by $\mathbf{d} = \boldsymbol{\lambda/4}$ and is thus directly proportional to the wavelength of the light, perfect cancelation is only possible at one wavelength. Or, in other words, an AR coating is wavelength dependent. For example, a glass with refractive indices $\mathbf{n_{substrate} = 1.52}$ and $\mathbf{n_{air} = 1}$ as the surrounding medium, would require a coating material with refractive index $\mathbf{n_1 = \sqrt{1 \cdot 1.52} = 1.23}$. Since such a material is not available for a reliable coating,

MgF_2 with a refractive index of **1.38** is used and some back reflections are accepted. For this type of AR coating at 500 nm, a thin-film layer thickness of d = 500 nm/(4 · 1.38) = 90.5 nm is needed. The wavelength dependency and residual back reflection at 500 nm can be seen in **Fig. 2.4**.



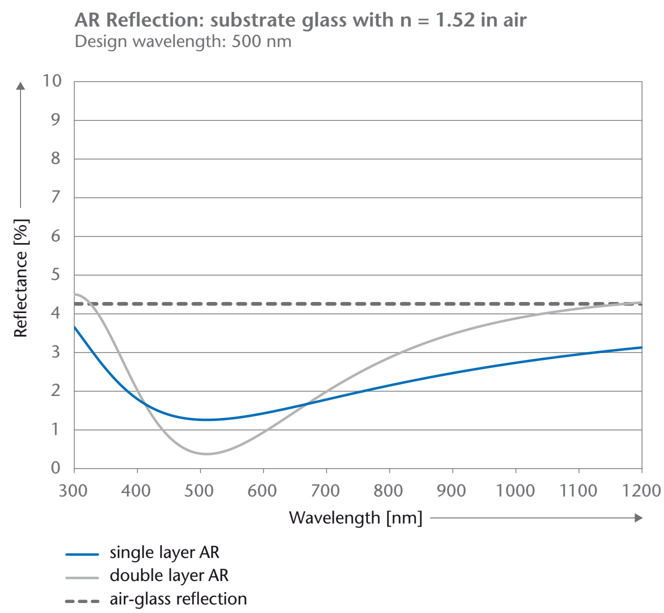


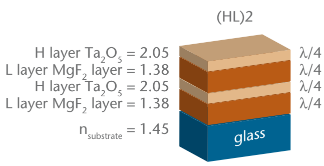
Fig. 2.4
A single layer MgF_2 AR coating reduces the air-glass reflectance from 4.3 % to 1.3 % at 500 nm. A double layer AR coating further reduces the reflectance to 0.4 % on the expense of stronger wavelength dependency.

For further reduction of the residual reflectance, a second AR layer can be added. The first λ/4 layer must be made of a different material with a different refractive index, e.g. Al_2O_3 with **n = 1.60** at 500 nm. If both λ/4 layers are made of the same material, then both layers add to a λ/2 absentee layer with no optical effect at 500 nm and the reflectance would again be 4.2 % at 500 nm. Thus, the 2 layer AR coating consists of a medium refractive index λ/4 layer and a low refractive index λ/4 layer.

2.1 All dielectric interference filter (ADI filter)

As described, a 2 layer AR coating consists of a low refractive index λ/4 layer and a high refractive index λ/4 layer. As an abbreviation, this is referred to as LH, where L represents the low and H the high refractive index λ/4 layer. Such **λ/4 layers** are the **basic building blocks** of interference filters[1]. For example the addition of two alternating H and L layers results in the abbreviation (HL)2, where (HL)2 means HL-HL design. This (HL)2 layer design is shown on the left side in **Fig. 2.5** together with the effect of many (HL) building block layers on the reflectance spectrum.

[1] For more details, please refer to Angus Macleod: "Thin-Film Optical Filters," 4th edition, CRC Press, New York 2010.



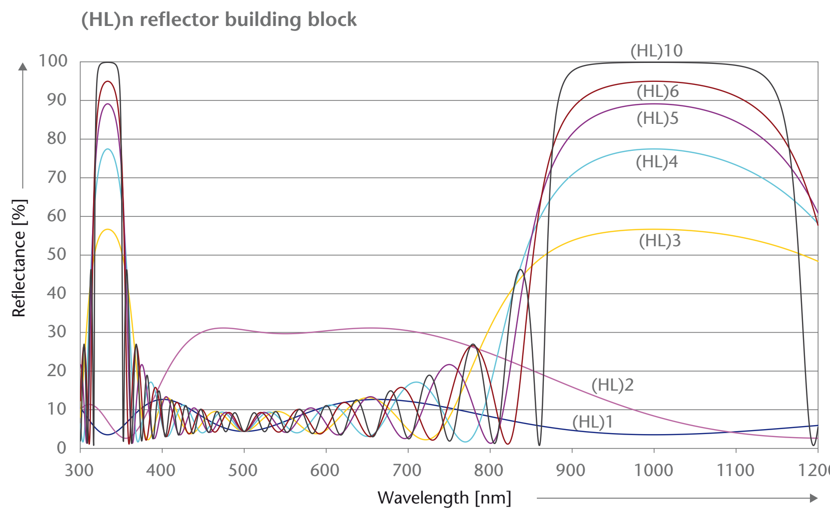


Fig. 2.5
Reflectance spectrum of (HL) n layers from a simple (HL) building block towards an (HL)10 building block from 300 nm to 1200 nm. The design above shows the set-up of a (HL)2 layer design on a glass substrate with a refractive index of $n_{substrate}$ = 1.45. The H layer has a refractive index of 2.05 made out of Ta_2O_5 and the L layer a refractive index of 1.38 made out of MgF_2 at a design wavelength of 1000 nm.

In order to visualize the interference filter made from an (HL)10 design, **Fig 2.5** is shown as transmittance spectra in **Fig. 2.6**. Such an (HL)10 design consists solely of dielectric layers with different refractive indices and is therefore called an **all dielectric interference filter (ADI)**.

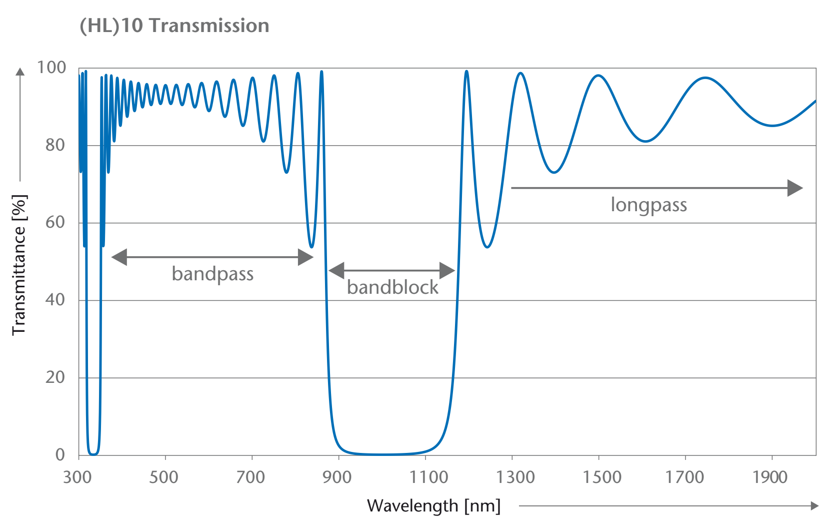


Fig. 2.6
Transmittance spectrum of a (HL)10 design, also called all dielectric interference filter (ADI), from 200 nm to 2000 nm. Depending on the operating wavelength, a bandpass filter, bandblock filter, or longpass filter will result. The design parameters are the same as in **Fig. 2.5**.

A narrow bandpass ADI filter can be produced by adding a λ/2 layer (absentee layer) inside the bandblock. The absentee layer allows the design wavelength to pass through the filter and to generate a narrow bandpass filter. For example, a simple bandblock is generated from an (HL)8 design where a glass of refractive index $n_{substrate}$ = 1.52, H layer made of Ta_2O_5 and L layer made out of SiO_2 at 550 nm design wavelength were used. The narrow bandpass filter design with 2H as the λ/2 narrow bandpass layer is:

Air-(HL)4–2H–(LH)4 - glass.

The design is illustrated in **Fig. 2.7**.

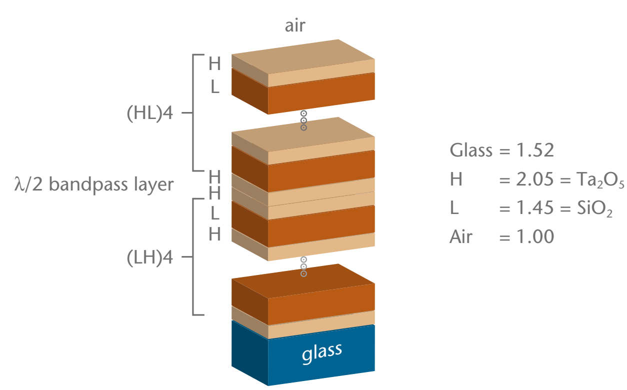


Fig. 2.7
Illustration of the narrow bandpass filter design with (HL)4–2H–(LH4).

The (HL)8 bandblock and (HL)4–2H–(LH)4 narrow bandpass filter design generate the transmittance spectra shown in **Fig. 2.8**.

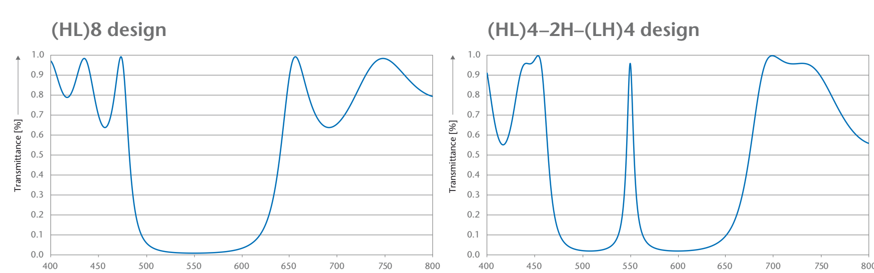


Fig. 2.8
Transmittance spectrum of an (HL)8 design (left) and a narrow bandpass filter design with a 2H bandpass layer (right) with design (HL)4–2H–(LH4).

2.2 ADI filters with cavities

The narrow bandpass filter consists of the design (HL)4–2H–(LH)4, a single cavity. Adding a second cavity, i.e. (HL)4 –2H – (LH)4 with a coupling layer L in between has the following design:

Air-(HL)4–2H–(LH)4–L–(HL)4–2H–(LH)4–glass.

This type of 2 cavity design improves the narrow bandpass resulting in steeper edges as well as a flatter passband, as can be seen in **Fig. 2.9**.

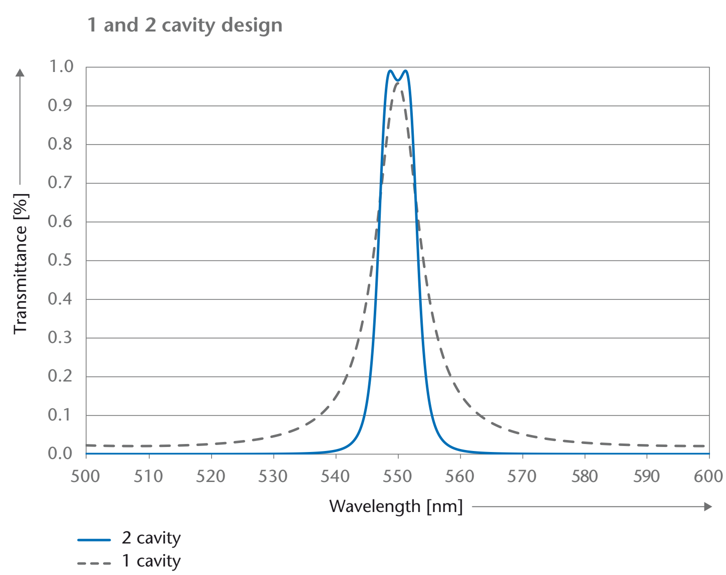


Fig. 2.9
Transmittance spectrum of an ADI filter from 500 nm to 600 nm for a single cavity design and a 2 cavity design. The 2 cavity design improves the narrow bandpass and has steeper edges as well as a flatter passband at 550 nm.

Increasing the number of cavities results in better performance of the narrow bandpass filter and changes the shape of the spectral transmittance curve from triangular to rectangular (see **Fig. 2.9**). At the same time, the curves get steeper and the inherent blocking outside the bandpass range increases.

The standard program of bandpass interference filters includes filters with two and three cavities. Filters with up to ten cavities and more are produced as special filters and broadband and blocking filters. Such custom-made filters make up a good share of the production program.

Examples of multi-cavity ADI filters are our DAX filters such as FITC-A/E.

2.3 Metal-dielectric interference filter (MDI filter)

Metallic layers reflect almost all light as we have seen with mirrors since the Middle Ages. The reflectance of aluminum is shown in **Fig. 2.10**.

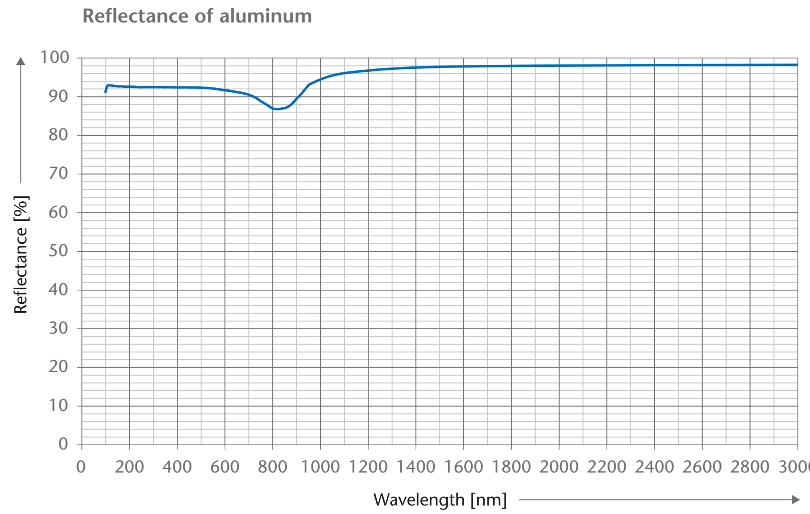


Fig. 2.10
Reflectance of aluminum[2].

Glass with a metal layer made of aluminum reflects light over the entire visible spectrum (380 nm to 780 nm) and deeply into the Infrared. Light in the UV range from about 150 nm to 300 nm is reflected (broad reflection in the UV is difficult to achieve with dielectric layers) and light in the IR with a wavelength of more than 1000 nm is also reflected as can be seen in **Fig. 2.10**. UV interference filters are thus one possible application of metal layers. Due to the broad reflectance spectrum, filters made of metallic layers have an inherent broad blocking spectrum.

Adding a second reflector spaced by a dielectric phase matching layer (also called spacer layer) generates a so-called Fabry-Perot resonator if the phase matching layer has the proper thickness (close to $\lambda/2$), see **Fig. 2.11**. For the design wavelength (with correct spacer layer thickness), the 2 waves with reflection $\mathbf{r_1}$ and $\mathbf{r_2}$ interfere constructively and the light will be transmitted. This assumes that the metallic layer reflects only part of the light. The top reflector can be made of (HL) n dielectric layers – compared with **Fig. 2.5** where light with a wavelength ranging from around 900 nm to 1150 nm of a (HL)10 design is reflected nearly completely.

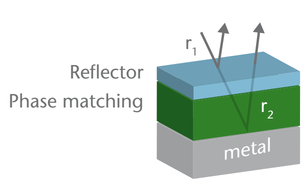


Fig. 2.11
A reflector separated by a phase matching layer on top of a metal layer generates a Fabry-Perot resonator.

[2] Edward D. Palik: "Handbook of Optical Constants of Solids," Academic Press, San Diego, USA, 1991.

Such a single phase matching layer design behaves like a narrow bandpass filter and its performance can be increased by adding more metallic layers separated by a phase matching (spacer) layer as it was described in section 2.2.

These filters are called **metal-dielectric interference (MDI) filters** and are mainly manufactured as bandpass filters. Their multilayer system consists mainly of thin, partially-transmitting metal layers separated by essentially absorption-free dielectric spacer layers. The thickness of the spacer layers mainly determines the spectral position λ_1 of the passband with the longest wavelength.

Further passbands are obtained at wavelengths of around $\lambda_k = \lambda_1/k$ (k = 2, 3, 4… in the case of low-index spacers[3] e.g. in KMZ 50) due to the periodicity of a Fabry-Perot resonator. Wavelength λ_1 is also referred to as the first-order wavelength, λ_2 as the second-order wavelength, and so on. Because the refractive indices of the spacer layer materials are dependent on wavelength, the above equation can only be an approximation for the spectral position of higher order passbands, as illustrated in **Fig 2.12**.

MDI filters possess a broader inherent blocking range than non-blocked ADI bandpass filters with comparable bandpass characteristics. However, due to the absorption exhibited by the metal layers, MDI filters typically have lower maximum transmittance than ADI filters. The elimination of undesirable passband orders with MDI filters is achieved by means of additional blocking filters.

Examples of MDI filters in our program are KMD 12, DMZ 12 or KMZ 20 filters.

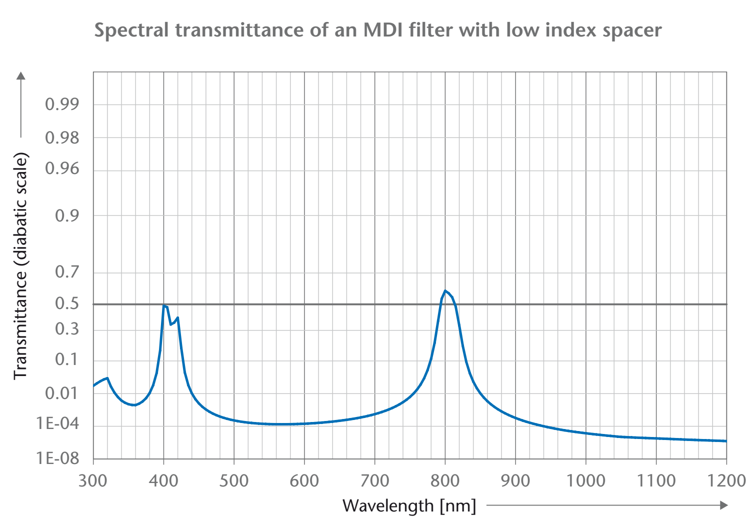


Fig. 2.12
An MDI filter curve (filter KMZ 35) with low index spacer shows the first-order wavelength of around 800 nm and the second-order wavelength of around 400 nm.

[3] In the case of high index layers, further passbands are obtained for approximately $\lambda_k = \lambda_1/k$ (k = 1.5, 2.5, 3.5, …), e.g. KMZ 20 filters.

i-line bandpass filter with 160 mm diameter
transmitting light at a wavelength of 365 nm
used in lithography.

3. Definitions used with interference filters

Optical filters transmit a certain wavelength band, while other wavelength bands are being blocked. This selective transmittance of an optical filter is characteristic and therefore a quantitative measure of the optical filter. Filters typically consist of a plane parallel plate (plano-plano).

3.1 Spectral transmittance $\tau(\lambda)$

The spectral transmittance $\tau(\lambda)$, where λ is the wavelength in vacuum, is defined as the ratio of the transmitted (energetic) radiant flux $\Phi_{e,transmitted}$ to the incident (energetic) radiant flux $\Phi_{e,incident}$:

$$\tau(\lambda) = \frac{\Phi_{e,transmitted}}{\Phi_{e,incident}}$$

This is illustrated in **Fig. 3.1**.

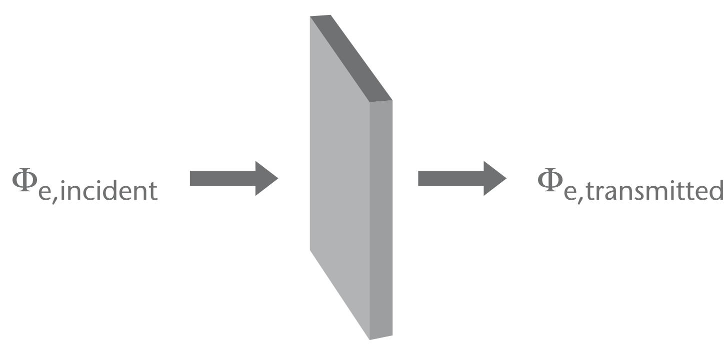


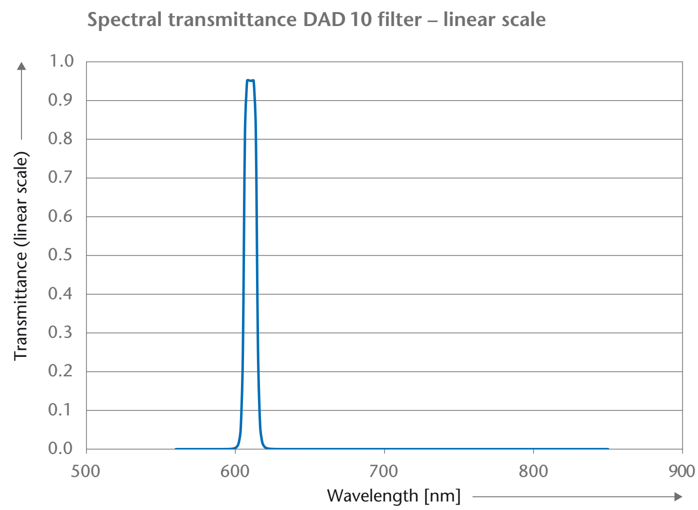
Fig. 3.1
Optical filter irradiated with incident radiant flux $\Phi_{e,incident}$ and the transmitted radiant flux $\Phi_{e,transmitted}$ for the definition of spectral transmittance $\tau(\lambda)$.

3.2 Spectral diabatie $\Theta(\lambda)$

It is advisable to use a derived form of the spectral transmittance, the so-called **spectral diabatie** $\Theta(\lambda)$. The spectral diabatie is defined as:

$$\Theta(\lambda) = 1 - \lg\left\{\lg\left[\frac{1}{\tau(\lambda)}\right]\right\}$$

where "**lg**" denotes the logarithm to base 10. The diabatic form offers a significant advantage over the linear form: both the passband (at high transmittance) as well as the blocking band (with low transmittance) are stretched. Thus both the passband and the blocking band can be seen clearly, as demonstrated in **Fig. 3.2**.



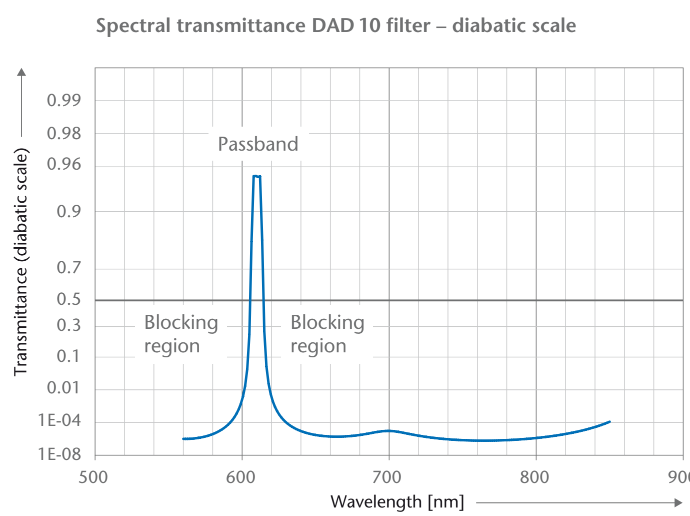


Fig. 3.2
Linear (top) and diabatic (bottom) illustration of spectral transmittance for the same bandpass filter (DAD 10). The diabatic scale (bottom) stretches both the passband and the blocking region and ensures that the optical filter is characterized properly.

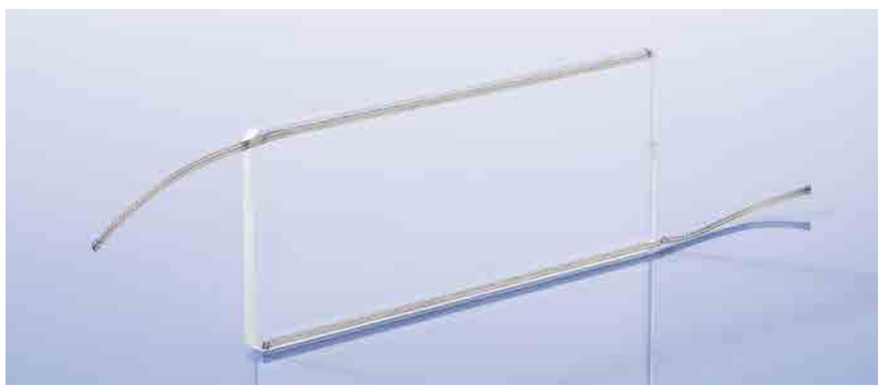
It should be noted that the definition of spectral diabatie for **interference filters** use spectral transmittance and a capital Greek theta (Θ) as a symbol.
Optical filter glass, on the other hand, uses **internal** spectral transmittance as the definition with a small Greek theta symbol (θ).

3.3 Spectral optical density D(λ)

In some cases the quantitative characterization of a filter is described in terms of spectral optical density D(λ). The relationship of spectral optical density to spectral transmittance is ruled by the equation:

$$D(\lambda) = -\lg\{\tau(\lambda)\}$$

where "**lg**" denotes the logarithm to base 10. This form of optical density offers a special advantage in the blocking region. For example, instead of a blocking of τ = **10^{-5}** at a certain wavelength, one obtains an optical density of **D = 5**.



Coated glass with a transparent conducting oxide, which is both transparent and electrically conducting.

3.4 Characterization of bandpass filters

Bandpass filters transmit a certain wavelength band, i.e. are characterized by having a range of high transmittance (passband) bounded both towards the shorter and longer wavelengths by ranges of low transmittance (blocking ranges), see **Fig. 3.3**.

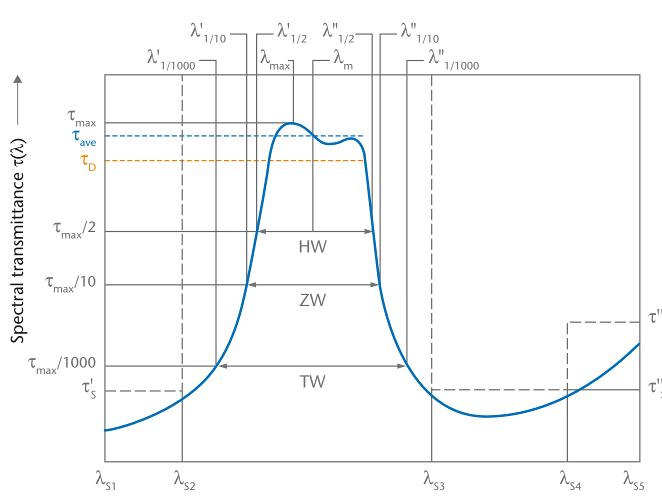


Fig. 3.3
A bandpass filter that transmits a certain wavelength band and shows characteristic values (defined below).

The most important properties of bandpass filters are defined using the following values (see also **Fig. 3.3**):

τ_{max}:	Maximum value of spectral transmittance within the passband (peak transmittance)
τ_D:	Minimum value of spectral transmittance within the passband
τ_{ave}:	Mean (average) value of spectral transmittance within the passband (typically defined between two wavelengths in the passband)
λ_m:	Center wavelength: If $\lambda'_{1/2}$ and $\lambda''_{1/2}$ are the wavelengths at which spectral transmittance is $\frac{\tau_{max}}{2}$ than $\lambda_m = \frac{\lambda'_{1/2} + \lambda''_{1/2}}{2}$
λ_{max}:	Wavelength at which the filter reaches maximum spectral transmittance τ_{max} (peak wavelength)
$HW = \Delta\lambda_{1/2}$:	Full width at half maximum (**FWHM**) = width of the transmittance curve at $\frac{\tau_{max}}{2}$ If $\tau(\lambda'_{1/2}) = \tau(\lambda''_{1/2}) = \frac{\tau_{max}}{2}$ than $HW = \Delta\lambda_{1/2} = \lambda''_{1/2} - \lambda'_{1/2}$
$ZW = \Delta\lambda_{1/10}$:	Tenth width = width of the transmittance curve at $\frac{\tau_{max}}{10}$ If $\tau(\lambda'_{1/10}) = \tau(\lambda''_{1/10}) = \frac{\tau_{max}}{10}$ than $ZW = \Delta\lambda_{1/10} = \lambda''_{1/10} - \lambda'_{1/10}$
$TW = \Delta\lambda_{1/1000}$:	Thousandth width = width of the transmittance curve at $\frac{\tau_{max}}{1000}$ If $\tau(\lambda'_{1/1000}) = \tau(\lambda''_{1/1000}) = \frac{\tau_{max}}{1000}$ than $TW = \Delta\lambda_{1/1000} = \lambda''_{1/1000} - \lambda'_{1/1000}$
$S_{\%}$:	Slope of filter in percent, defined by: $S_{\%} = \frac{\lambda_{80\,\%\text{ of peak}} - \lambda_{5\,\%}}{\lambda_{5\,\%}} \cdot 100$, where $\lambda_{80\,\%\text{ of peak}}$ is the wavelength at which the transmittance is 80 % of τ_{max} (correspondingly $\lambda_{5\,\%}$ wavelength where transmittance is 5 % of τ_{max}). The slope characterizes the steepness of the short wavelength edge and the long wavelength edge and thus 2 values are defined.
Q value:	$Q = \frac{\text{Tenth width}}{\text{Half width}} = \frac{\Delta\lambda_{1/10}}{\Delta\lambda_{1/2}} = \frac{ZW}{HW}$
q value:	$q = \frac{\text{Thousandth width}}{\text{Half width}} = \frac{\Delta\lambda_{1/1000}}{\Delta\lambda_{1/2}} = \frac{TW}{HW}$
τ_{SM}:	Mean (average) value of spectral transmittance within the blocking range. In the case of bandpass interference filters that are specified as having an “unlimited” blocking range (see also “Blocking range unlimited,” section 3.6), the end of the sensitivity range of a commonly used detector is taken as the long-wave limit, when τ_{SM} is evaluated.
τ_S:	Upper limit for spectral transmittance within the blocking range
τ'_S, τ''_S etc.:	Upper limits for spectral transmittance within blocking ranges from λ_{S1} to λ_{S2}, from λ_{S3} to λ_{S4} etc.

3.5 Characterization of edge filters

Edge filters are characterized by having a range of high transmittance (passband) followed by a range of low transmittance (blocking range) or vice versa. There are two types of edge filters:

- **Shortpass filters** pass a shorter wavelength band i.e. have a range of high transmittance of shorter wavelengths than the blocking range.
- **Longpass filters,** on the other hand, pass a longer wavelength band (see **Fig. 3.4**), i.e. have a range of high transmittance of longer wavelengths than the blocking range.

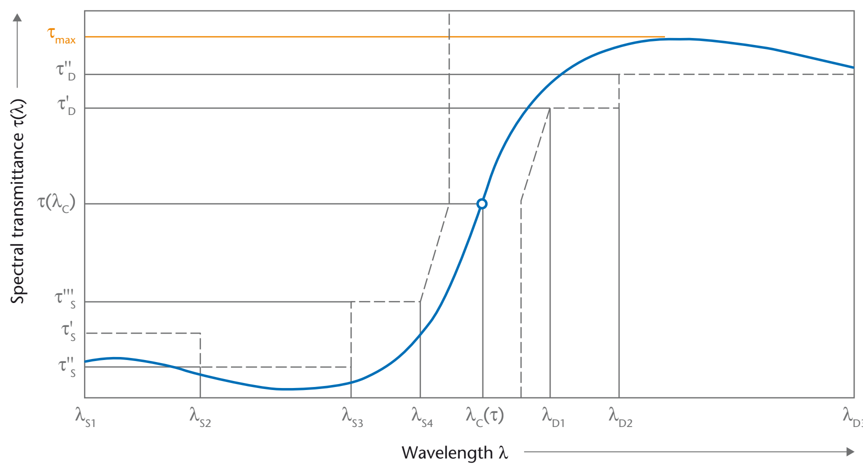


Fig. 3.4
A longpass filter as an example of an edge filter type and characteristic values.

The main properties of edge filters are defined by (compare with **Fig. 3.4**):

τ_{max}:	Maximum value of spectral transmittance within the passband (peak transmittance)
λ_C:	Edge wavelength, whereby spectral transmittance reaches a certain specific value, e.g. $\tau(\lambda_C) = 0.50$
τ_{DM}:	Mean (average) value of spectral transmittance within the passband
λ_D:	Minimum value of wavelength within the passband
τ'_D, τ''_D etc.:	Minimum values of spectral transmittance within the passband from λ_{D1} to λ_{D2}, from λ_{D2} to λ_{D3}, etc.
τ_{SM}:	Mean (average) value of spectral transmittance within the blocking range
τ_S:	Upper limit for spectral transmittance within the blocking range
τ'_S, τ''_S etc.:	Upper limit for spectral transmittance within blocking ranges λ_{S1} to λ_{S2}, from λ_{S2} to λ_{S3}, etc.
$S_{\%}$:	Slope of filter in percent, defined by: $S_{\%} = \frac{\lambda_{80\,\%\text{ of peak}} - \lambda_{5\,\%}}{\lambda_{5\,\%}} \cdot 100$, where $\lambda_{80\,\%\text{ of peak}}$ is the wavelength at which the transmittance is 80 % of τ_{max} (correspondingly $\lambda_{5\,\%}$ wavelength where transmittance is 5 % of τ_{max}).

3.6 Blocking range unlimited

This specification indicates that the short-wave blocking range extends from wavelengths below 100 nm up to the beginning of the passband. The long-wave blocking range extends from the end of the passband into the far infrared (wavelengths above 50 µm). Hence, for normal practical applications, the blocking range can be said to be unlimited.

3.7 Blocking range up to …

This specification indicates that the short-wave blocking range extends from wavelengths below 100 nm up to the beginning of the passband. The long-wave blocking range extends from the end of the passband at least to the wavelength specified.

3.8 Blocking

Blocking is the additional attenuation of the radiation outside the filter's inherent blocking range by means of supplementary filters. Blocking is usually achieved by absorption and/or reflectance of the undesirable radiation.

Blocking of the interference filters described in this brochure can mostly be arranged in accordance with customers' needs. It is therefore possible to increase the maximum transmittance within the passband or to reduce the thickness of the filter in certain cases. Filters without any blocking are also available upon request.

3.9 Angle of incidence

The angle of incidence is the angle between the optical axis of the incident beam and the normal to the surface of the filter facing towards the incident beam. Hence, if the beam is perpendicular to the filter surface, the angle of incidence is 0°.

3.10 Plane of incidence

The plane of incidence is the plane defined by the optical axis of the incident beam and the normal to the surface of the filter. Hence, at an angle of incidence of 0°, no plane of incidence can be defined, as the optical axis and the normal to the surface of the filter coincide.

3.11 Angle of aperture

In the strict sense of the word, parallel radiation (perfect collimated beam) does not exist; there are, however, almost parallel (quasi-parallel or quasi-collimated) beams that form a more or less open cone.

The angle of aperture ϑ is **twice** the angle formed by the outer rays of the envelope cone of the incident beam and the optical axis (axis of symmetry) of the cone.

Taking into account the spectral properties of interference and optical glass filters, and the accuracy normally expected in this area, radiation can be regarded as being "parallel" (quasi-collimated) as long as the angle of aperture is about 5°. Such angles are common in spectrometers used for determining the spectral transmittance of optical radiation filters.

3.12 Polarization

In the case of electromagnetic radiation, the electric field vector oscillates perpendicular to the vector of propagation. This property is a characteristic of transverse waves.

The electric field vector and the vector of propagation together define the so-called plane of oscillation. Unpolarized radiation has no preference for a particular plane of oscillation (the electric field vectors are statistically distributed); however, when all electric field vectors oscillate in the same direction, linear polarized radiation results. When parallel linear polarized radiation falls on an area, e.g. the surface of an interference filter, at an angle of incidence greater than 0°, two limiting cases are possible:

1. The electric field vector oscillates parallel to the plane of incidence. This is known as **P-polarization** or **TM polarization**.
2. The electric field vector oscillates perpendicularly to the plane of incidence. This is known as **S-polarization** or **TE polarization**.

In the case of a linear polarized radiation incident on a surface at an angle of incidence of 0°, these differences do not exist, as a plane of incidence cannot be defined.

The spectral properties of interference filters more or less depend on the degree of polarization of the radiation involved, especially if the angle of incidence is large.

Combination of interference filters and cemented optical filter glass (color glass).

4. Properties of interference filters

The next chapter describes the most important properties such as angular dependence, temperature dependence, radiation resistance, laser-induced damage threshold, and mounting & operating of interference filters.

4.1 Angular dependence

Interference filters are typically designed for a defined angle of incidence of the illumination beam. If the angle of incidence or angle of aperture changes, then the optical properties of the interference filter will change. These changes of optical properties depend, among other things, on the spectral position of the filter, the state of polarization of the radiation, the materials used for the layers and the design of the filter system as a whole. Even filters of the same type can exhibit different degrees of angular dependence due to the fact that the system design that depends on the spectral position of the filter must vary in order to comply with the spectral specification.

The transmittance wavelength or **edge position of interference filters is principally shifted towards the shorter wavelengths for increasing angles of incidence**. If the beam is parallel and the angle of incidence α is small (the acceptable range for α being dependent upon the filter in question), then the shift of wavelength $\Delta\lambda$ towards a shorter wavelength is approximately given by:

$$\Delta\lambda \approx k \cdot \sin^2\alpha$$

where k is approximately constant for a certain filter and state of polarization. Interference filters can be adjusted to the desired spectral position by tilting the filter.

The influence of angle of aperture also displaces the edge position of the filter towards the shorter wavelengths. In the case of unpolarized radiation with an angle of incidence 0° and an aperture angle ϑ that is not too large the shift is about the same as with parallel unpolarized radiation with an angle of incidence $\alpha = \frac{\vartheta}{4}$. In addition, in the case of bandpass filters, increasing angles of aperture lead to both a broadening of the transmittance curve as well as a decrease in maximum transmittance. These effects generally occur to a greater extent with filters of narrower band widths than with those of larger band widths.

For most applications changes in spectral values are practically insignificant up to angles of incidence of about 5° with parallel irradiated beams and up to an angle of aperture of about 20° at normal incidence, with the exception of bandpass filters with half widths of less than 5 nm.

Because many different behaviors of properties are possible due to the influence of angle of incidence and angle of aperture, (shift of λ_m and λ_C, changes in spectral characteristic, influence of polarization, etc.), no attempt will be made here to cover all of these aspects. However, we would be glad to assist and advise you, if any further information on your filter is needed.

4.2 Temperature dependence

The spectral values specified for interference filters are related to a temperature T = 23 °C (room temperature). Depending on the type of the thin layers and the design of the entire layer system, the filters can exhibit different temperature dependences with regards to their spectral characteristics.

The integral of the passband curve and hence the signal received changes with temperature. Information on the change on the center wavelength or edge position is of special importance. Details are included in the "Properties" brochure.

The interference filters described in this brochure can be divided into five categories according to their temperature dependence:

1. **Interference filters made by magnetron sputtering (MS)**
   Due to the compact structure of the layers by magnetron sputtering, which practically excludes the absorption of moisture from the environment, only very slight thermal dependence is demonstrated. The value is mainly dependent on the layer materials and substrate material due to the different thermal expansion of the materials and the temperature dependence or their refractive indices. Measurements made with edge filters within the range 23 °C to 185 °C resulted in typical temperature coefficients $\frac{\Delta\lambda}{\Delta T}$ of approximately −0.003 nm/K to +0.005 nm/K.

   This type of interference filter is hence suited for applications where greater temperature changes are unavoidable but where changes in the spectral characteristics need to be minimized.

2. **Interference filters with soft coatings by electron beam (EB) evaporation**
   This group comprises bandpass filters of the standard program, VERIL linear variable filters and the filter types KMD, KMZ, DMZ, MAZ, MAD, and DAD.

   A shift towards the longer wavelengths usually takes place when temperatures rise. The temperature coefficient $\frac{\Delta\lambda}{\Delta T}$ is typically within the range +0.007 nm/K to +0.03 nm/K.

3. Interference filters with hard coatings by hot reactive electron beam (EB) evaporation

A shift towards the shorter wavelengths generally takes place when temperatures rise. In the temperature range 20 °C to 100 °C, the mean temperature coefficient $\frac{\Delta\lambda}{\Delta T}$ is approximately −0.15 nm/K. In the temperature range 100 °C to 250 °C, the mean temperature coefficient $\frac{\Delta\lambda}{\Delta T}$ is approximately −0.05 nm/K. This temperature dependence is generally acceptable for coatings that have broadband characteristics used in anti-reflective and mirror systems. Please see section 5 (Coating processes) to learn more about the advantages of this process.

4. Interference filters with hard coatings by ion assisted deposition (IAD)

Generally, a shift towards the longer wavelengths takes place as the temperature increases. In the temperature range 20 °C to 250 °C, the mean temperature coefficient $\frac{\Delta\lambda}{\Delta T}$ is approximately between −0.003 nm/K and +0.005 nm/K. This can vary depending on the choice of layer materials and substrate material.

Due to the variability of ion assistance, the thermal dependence can be influenced. If a customer needs a special temperature dependence within the range cited, we can make improvements on the basis of fixed substrate and layer materials, as the temperature dependence in this range is due to the thermal expansion coefficient of substrate and layer materials.

5. Interference filters with hard coatings by reactive ion plating (IP)

Due to the compact structure of the layers, which practically excludes the absorption of moisture from the environment, only very little thermal dependence is demonstrated. The value is mainly dependent on the layer materials and substrate material due to the different thermal expansion of the materials and the temperature dependence or their refractive indices. Measurements made with edge filters within the range 23 °C to 185 °C resulted in typical temperature coefficients $\frac{\Delta\lambda}{\Delta T}$ of approximately −0.003 nm/K to +0.005 nm/K.

This type of interference filter is hence suited for applications where greater temperature changes are unavoidable but where changes in the spectral characteristics need to be minimized.

4.3 Resistance to radiation

Intensive radiation, e.g. concentrated UV and powerful laser radiation, can lead to permanent changes of the optical properties of interference filters and optical radiation filters in general or even destroy them. The degree of distortion or damage depends, among other things, on the specific design of the filter in question and the nature of the radiation involved, especially as far as its intensity distribution (with respect to wavelengths, time and spatial geometry) is concerned. Radiation tests under controlled conditions have shown that the UV interference filters described in this brochure in general offer good resistance to intensive UV radiation.

Due to the large number of different radiation characteristics that can occur during application, however, these results cannot necessarily be transferred to every experimental situation. Hence, in many cases, reliable data with respect to resistance to radiation can only be obtained by testing under the conditions to be expected during the application envisaged.

4.4 Laser-induced damage threshold (LIDT)

High laser power can damage an interference filter due to the extremely high electric field of the incident laser power. This high laser power can lead to absorption-driven damage (via absorption by defect sites inside the coating that generates heat, melting, stress, etc.) or dielectric breakdown damage (where suddenly the insulating dielectric layer becomes conductive due to the high electric field). Therefore, coating layers and processes with extremely low attenuation are generally needed.

Continuous wave (CW) lasers emit constant power (steady state) and exhibit a different LIDT than pulsed lasers. For pulsed lasers, the energy density (in J/cm^2) – also called fluence – is an important value for LIDT. Furthermore, peak power, pulse duration, and repetition rate should be known. Hence, the following information should be provided:

- Laser type: CW or pulsed laser
- Average power
- Beam diameter
- Wavelength of operation
- Pulse width (if a pulsed laser is used)
- Repetition rate (if a pulsed laser is used)

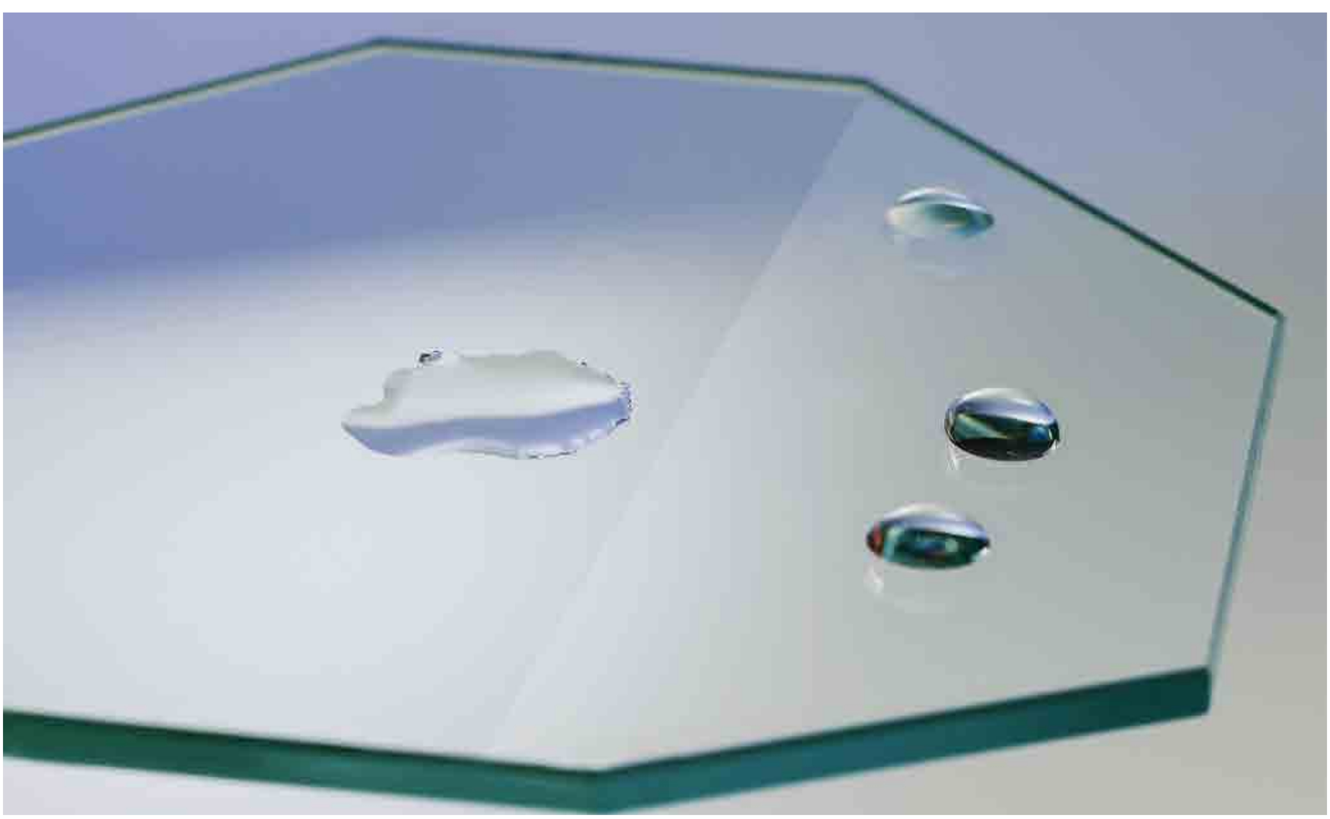
Based on this information and our experience, we will try to design and manufacture an appropriate optical coating that meets your exact needs.

4.5 Mounting and operating filters

Interference filters and optical filters in general should be fitted so that mechanical stress is avoided. The filters described here should not be exposed to temperatures higher than specified in the individual data sheets. To avoid unnecessary heating by radiation, filters with a reflective mirror side should be mounted with the mirror facing towards the irradiating light source.

The full filter area should be illuminated uniformly to avoid greater variations in temperature on the filter itself. The greater such temperature differences, the larger the danger that stresses will occur, which, especially in the case of cemented filters, can lead to permanent changes in the spectral specification and even breakage of the filter. The same principle applies to rapid changes in the filter temperature with respect to time.

Should applications be envisaged under conditions harsher than those described here, specific details should be included in your inquiry so that we can check whether these conditions can be fulfilled by using glasses with a higher degree of thermal stability or thermally tempered optical filter glasses.



Water drops on a uncoated (left) and hydrophobic coated (right) glass surface.

5. Coating processes

Interference coatings on SCHOTT's comprehensive materials are manufactured using different high vacuum coating deposition processes:

- Thermal or electron beam (EB) evaporation, cold or hot reactive
- Ion assisted deposition (IAD)
- Ion plating (IP)
- Magnetron sputtering (MS)

The choice of the respective process and manufacturing equipment to be used depends on considerations concerning layer material characteristics (refractive index, absorption, defect level, temperature dependence, etc.), process control (optical, quartz oscillator, time-power), substrate characteristics (dimensions, shape, temperature resistance) and, last but not least, costs (tooling, lot size, etc.).

Thermal or electron beam evaporation can be used for metals, soft layer materials (see below for details) and metal oxides on hot and cold substrates. This process is very versatile with respect to the choice of materials and change of processes during a production day. It also offers the most versatile tooling.

The so-called "soft" coatings are evaporated thermally or via electron beam evaporation on a cold substrate *(cold EB)*. They offer the broadest choice of refractive indices, especially for low indices, and excellent transmission in the UV range. For this reason, these coating materials are used for UV and special filter designs that require certain refractive indices: e.g. bandpass filter designs with tailored full width at half maximum or polarizing beam splitters. Additional measures are taken to protect the layers from damage by handling or moisture. This is usually achieved by cementing the coated surface to an appropriate glass. The upper temperature limit for these filters is essentially determined by the nature of the optical cement being used.

Within certain areas of the UV spectrum, it is impossible to use optical cements due to the inherent absorption involved. In such cases, the coated substrates are fitted into appropriate mounts and protected by appropriate glasses.

In the hot reactive type of electron beam evaporation, metal oxide materials are deposited onto a substrate at elevated temperatures (300 – 350 °C) and oxygen is added during the process *(hot reactive EB)*. This results in "hard" coatings that generally require no additional protection. Coatings manufactured using the hot reactive technique feature a columnar microstructure, which leads to a moisture take-up during the first 48 hours after manufacturing. This, in turn, results in a minimal spectral shift that can be reversed by baking in the coating. Depending on the substrate selected, interference filters with hard coatings made by hot reactive evaporation can be operated at temperatures of up to around 350 °C if the design and application can tolerate a small spectral shift (see section 4.2). This is generally the case with coatings that have broadband characteristics like AR systems and mirror systems.

Coatings made by using hot reactive electron beam evaporation can be produced nearly free of any contaminants. This is not the case when applying high energetic processes like ion assisted deposition, ion plating and magnetron sputtering.

Interference filters with hard layers by **ion assisted deposition**, **reactive ion plating** or **magnetron sputtering** are particularly well suited for applications where greater temperature changes or humidity are unavoidable but changes in the spectral characteristics are to be kept to a minimum. These hard coatings consist mainly of thin metal oxide layers and are very dense and resistant to external influences. Their microstructure is amorphous, which leads to practically no absorption of moisture from the environment. If an appropriate substrate is used (e.g. BOROFLOAT® borosilicate glass), these filters may be used at temperatures of up to approximately 350 °C.

In the process of **ion assisted deposition (IAD)** the layers evaporated by an electron beam are bombarded with an energetic ion beam of reactive ions (generally oxygen) during layer growth. The amount of ion assistance can be tailored to the desired film characteristics such as refractive index, density and stress in the coating.

In **reactive ion plating (IP)** the material is evaporated by an electron beam. In addition a highly energetic plasma beam is directed into the metal melt to result in a high fraction of ions in the gas phase. The particles that form a film are subsequently projected onto the substrate by bias-voltage applied to the substrate carrier. This results in a very dense film and high compressive stress, which leads to very durable and thermally stable coatings.

In a **magnetron sputtering (MS)** process a plasma is ignited in front of a magnetron cathode, that sputters (erodes) the target material bonded to that cathode. The particles that form the film traverse (cross) the plasma and deposit onto the substrate to form a dense and amorphous thin-film. This process can be performed with and without a reactive gas in combination with an additional plasma source to influence the layer stoichiometry. Metal layers as well as dielectric metal oxide layers can be deposited. The main advantage of magnetron sputtering is a very stable growth rate of the layers, which leads to a high degree of thickness control and the possibility of depositing many layers and immense overall layer thicknesses. Nevertheless, magnetron sputtered films can show non-negligible compressive stress especially in combination with greater layer thicknesses.

Magnetron sputtering enables the production of extremely hard, scratch-resistant AR-systems (e.g. on sapphire substrates), narrow bandpass filters or steep edge filters.

6. Custom-made filters

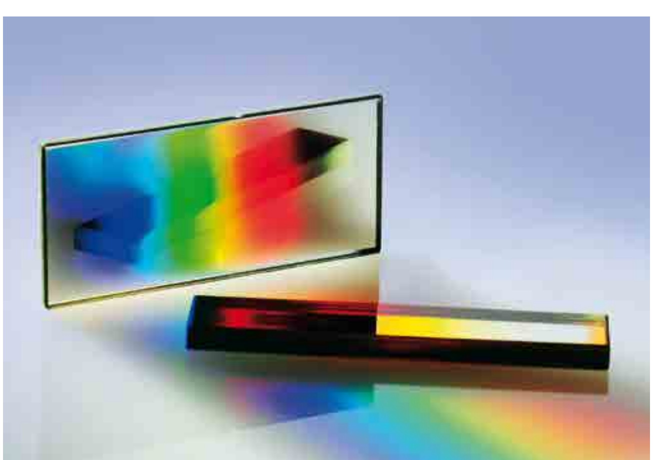
Many applications require interference filters with specific properties that are not available in our standard program. We would be more than pleased to discuss custom-made filter solutions with you.

The development and production of interference filters with specific properties that meet customers' specifications make up the greater part of our product line. It is also possible to have your own substrates coated on demand; however, we would like to point out that we are unable to assume any responsibility for possible breakage that might occur.

Custom-made filters are not only characterized by their specific spectral values but also by other parameters such as dimensions, special surface properties, thermal stability, increased stability against severe environmental influences, etc.

If you are in need of filters for your own particular applications with specifications that are not covered by our standard program, we would ask that you provide us with as many details as possible regarding the optical and non-optical properties you need in the form of technical drawings, for instance.

For the purpose of specifying your requirements, we also recommend filling out the questionnaires at the beginning of the "Properties" brochure. Please complete these and send them to us for checking and comments. We will then come back to you with either a specific cost quotation or an alternative suggestion.



A VERIL filter, bandpass filters with variable (over length) center wavelength.

A partly coated disc: a scratch-resistant AR coating (upper left) and an uncoated surface (lower right).

7. Applications

The following chapter gives a general overview of applications which utilize interference filters. Most of our interference filters are customized. Some applications of these filters are as follows.

Fluorescence spectroscopy typically requires steep bandpass filters and a dichroic beam splitter. The absorbed light coming from the light source is separated from the emission light from the sample under investigation with the help of steep bandpass filters.

Such steep bandpass filters are also used in **Raman spectroscopy**. If strong light is incident on a sample than the sample can scatter light due to the Raman-effect. This scattered light is typical for the sample under investigation. Raman spectroscopy requires steep edge filters, notch filters, and narrow bandpass filters.

Lithography uses for example UV-light at 365 nm (so-called i-line). SCHOTT offers narrow bandpass filters for applications in i-line steppers. The filter is coated with various layers and this tailored multilayer system is characterized with an outstanding transmission at 365 nm combined with a narrow spectral bandwidth and very good homogeneity of the spectral behavior throughout the usable filter area.

For **safety & security** applications such as digital surveillance cameras require IR cut filters that absorb the IR light. Only the visible light passes an IR cut filter which is often a combination of a blue filter glass and an additional interference filter as well as AR coating.

Medical & biotechnology applications require UV bandpass filters as well as edge filters to increase the signal-to-noise ratio of spectroscopic measurements.

In **analytic applications** a VERIL linear variable interference filter is used. Its central position of the center wavelength λ_m of the narrow passband changes constantly over the length of the filter.

In **industrial applications** our dielectric mirrors are used as laser mirrors due to the low absorption of this coating.

Astronomy applications require steep edge bandpass filters and very stable characteristics which can be met by our interference filters used in astronomical instrumentation.

8. General comments

Details on all of the interference and special filters described in this brochure including their optical and non-optical properties, are listed in the "Properties" brochure. Data qualified by approximation or not accompanied by tolerance values is to be understood only as guidelines (approximate values).

The following also applies to all individual descriptions of filter types:
All spectral values given are based on room temperature of 23 °C in conjunction with quasi-parallel (= quasi-collimated) radiation (angle of aperture approximately 5°) and an angle of incidence of 0°.

The spectral (internal) transmittance curves shown are to be understood as general curves for orientation purposes only.

The measured spectral transmittance or reflectance curves (spectral transmittance $\tau(\lambda)$ linear from 0 to 1) for individual filters can be supplied upon request.

Specialized, custom-made filters make up the greater part of our product portfolio. If you are in need of filters with specifications that exceed those included in this brochure, we would suggest that you define these as clearly as possible. Here, we highly recommend that you fill out the **questionnaires** that can be found in the "Properties" brochure.

Black chrome coated substrates on top of
a chrome-plated metallic surface.

9. Your global contacts

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SCHOTT
glass made of ideas

Interference Filters & Special Filters

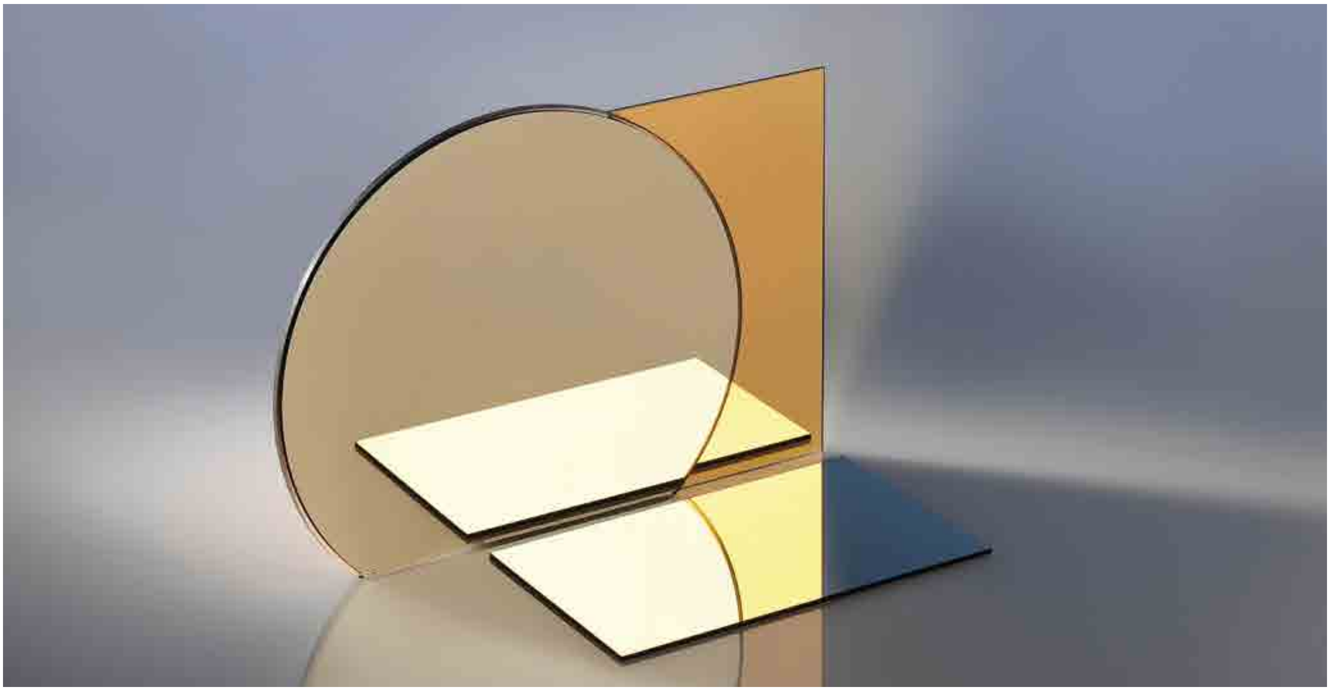
Properties - 2015

SCHOTT is an international technology group with more than 125 years of experience in the areas of specialty glasses and materials and advanced technologies. With our high-quality products and intelligent solutions, we contribute to our customers' success and make SCHOTT part of everyone's life.

SCHOTT Advanced Optics, with its deep technological expertise, is a valuable partner for its customers in developing products and customized solutions for applications in optics, lithography, astronomy, opto-electronics, life sciences, and research. With a product portfolio of more than 120 optical glasses, special materials and components, we master the value chain: from customized glass development to high-precision optical product finishing and metrology.

SCHOTT: Your Partner for Excellence in Optics.

Title
Dielectric mirror coatings.



Contents

1. SCHOTT interference product range

SCHOTT was one of the inventors of interference filters dating back since 1939. Based on this long history of experience the filter portfolio is suited to fit all applications of our customers. Most of our interference filters are designed to meet customers' specifications. Besides interference filters SCHOTT provides also optical filter glass, or a combination of interference filters and optical filter glass. The interference and special filter portfolio of SCHOTT includes the following types of filters:

- Longpass interference filters
- Shortpass interference filters
- Bandpass interference filters
- Neutral density thin-film filters
- Notch filters
- Beam splitters
- Polarizing beam splitters
- Black chrome coatings
- AR coatings: V-coating, broadband, multi-band, hard or scratch-resistant
- Transparent conductive oxide coating
- Linear variable filters
- Dielectric (laser) mirrors
- Metallic mirrors

In addition we offer barrier coatings like humidity resistant, scratch-resistant, or anti-fingerprint coatings.

Besides the filters mentioned in this "Properties" brochure we offer **customized interference filters**. Actually most of our filters are customized and we would be glad to assist you with our experienced team to find the right filter solution for your application. Please do not hesitate to contact us at an early stage of your development.

The following pages hold questionnaires on all individual filter types which should be used in order to place a request. The inquired data helps us to select the optimized filter for you and provide a customized solution reflecting your requirements.

Combinations of interference filters and optical filter glass are also part of our portfolio. Such combinations can be used for:

- Linear variable filters (VERIL), using filter glass and an additional interference filter coating
- Tristimulus filters using filter glass combinations
- Bandpass filters with broad band rejection achieved by filter glass with interference filter

2. General information on listed data

All data listed in this "Properties" brochure are to be understood as reference values. Guaranteed values are only those values listed in this "Properties" brochure.

The graphically depicted transmittance curves serve as an initial overview to aid you in finding the most suitable optical filter type for your application.

Unless otherwise indicated, all data are valid for a temperature of 23 °C.

Upon inquiry, the reference values can be more closely specified and the guaranteed values can be adapted to your requirements, where possible.

We constantly strive to improve our products to your advantage through innovation and new technical developments. Therefore, we reserve the right to change the optical and non-optical data of our filters without prior notice.

The release of this brochure replaces all previous publications.

The new brochures were assembled with the utmost care; however, we assume no liability in the unlikely event that there are content or printing errors.

The abbreviations:

- **UV** stand for ultra-violet and corresponds approximately for wavelengths below 400 nm
- **VIS** stand for visible light and corresponds approximately for wavelength range between 380 nm and 780 nm
- **IR** stand for infrared and corresponds approximately for wavelengths above 800 nm

3. Questionnaire Bandpass filter

Please copy and enter your specific requirements.

Spectral filter values		
Center wavelength	λ_m =	[nm]
Tolerance of cwl	= ±	[nm]
Half width [nm] (HW = full width at half maximum)	HW =	
Tolerance of HW	= ±	[nm]
Peak transmittance within passband	$\tau_{max} \geq$	
$\frac{\text{Tenth width}}{\text{Half width}}$	Q approx.	
$\frac{\text{Thousandth width}}{\text{Half width}}$	q approx.	
Blocking range, short-wave	from λ_{S1} = to λ_{S2} =	[nm] [nm]
Upper transmittance limit within short-wave blocking range	τ'_S =	
Blocking range, long-wave	from λ_{S3} = to λ_{S4} =	[nm] [nm]
Upper transmittance limit within long-wave blocking range	τ''_S =	
Dimensions, with tolerances		
External dimensions:		[mm]
Size of utilizable area:		[mm]
Maximum thickness:		[mm]
Requirements		
Quantity:		[pcs]
Required delivery date:		
Are repeat orders to be expected?		[pcs/a]
Inquiry from:		

Application/problem	
Kind of radiation/source:	
Kind of detector:	
Optical arrangement	**Polarization state of radiation**
Angle of incidence:	☐ unpolarized
Angle of aperture:	☐ p-polarized
☐ photometric beam ☐ imaging beam	☐ s-polarized
Operating conditions	
Maximum operating temperature:	
Other operating conditions:	
Additional demands or wishes	
Quality documents	
Measurement documents:	☐ curve per lot ☐ label per filter (λ_m, HW, τ_{max})
☐ transmission ☐ reflection ☐ blocking (logarithmic)	
Other quality-documents:	

4. Questionnaire Shortpass filter

Please copy and enter your specific requirements.

Spectral filter values		
Edge wavelength	λ_c =	[nm]
Tolerance of λ_c	= ±	[nm]
Transmittance at λ_c	$\tau(\lambda_c)$ =	
1st passband	from λ_{D1} = to λ_D =	[nm] [nm]
Minimum passband transmittance in 1st passband	τ'_D =	
2nd passband	from λ_{D1} = to λ_D =	[nm] [nm]
Minimum passband transmittance in 2nd passband	τ'_D =	
1st blocking range	from λ_{S1} = to λ_{S2} =	[nm] [nm]
Upper transmittance limit within 1st blocking range	τ'_s =	
2nd blocking range	from λ_{S3} = to λ_{S4} =	[nm] [nm]
Upper transmittance limit within 2nd blocking range	τ''_s =	
3rd blocking range	from λ_{S5} = to λ_{S6} =	[nm] [nm]
Upper transmittance limit within 3rd blocking range	τ'''_s =	
Dimensions, with tolerances		
External dimensions:		[mm]
Size of utilizable area:		[mm]
Maximum thickness:		[mm]
Requirements		
Quantity:		[pcs]
Required delivery date:		
Are repeat orders to be expected?		[pcs/a]
Inquiry from:		

Application/problem	
Kind of radiation/source:	
Kind of detector:	
Optical arrangement	**Polarization state of radiation**
Angle of incidence: Angle of aperture: ☐ photometric beam ☐ imaging beam	☐ unpolarized ☐ p-polarized ☐ s-polarized
Operating conditions	
Maximum operating temperature:	
Other operating conditions:	
Additional demands or wishes	
Quality documents	
Measurement documents:	☐ curve per lot ☐ label per filter (λ_c, HW, τ_{max})
☐ transmission ☐ reflection ☐ blocking (logarithmic)	
Other quality-documents:	

5. Questionnaire Longpass filter

Please copy and enter your specific requirements.

Spectral filter values		
Edge wavelength	λ_c =	[nm]
Tolerance of λ_c	= ±	[nm]
Transmittance at λ_c	$\tau(\lambda_c)$ =	
1st passband	from λ_{D1} = to λ_D =	[nm] [nm]
Minimum passband transmittance in 1st passband	τ'_D =	
2nd passband	from λ_{D1} = to λ_D =	[nm] [nm]
Minimum passband transmittance in 2nd passband	τ'_D =	
1st blocking range	from λ_{S1} = to λ_{S2} =	[nm] [nm]
Upper transmittance limit within 1st blocking range	τ'_s =	
2nd blocking range	from λ_{S3} = to λ_{S4} =	[nm] [nm]
Upper transmittance limit within 2nd blocking range	τ''_s =	
3rd blocking range	from λ_{S5} = to λ_{S6} =	[nm] [nm]
Upper transmittance limit within 3rd blocking range	τ'''_s =	
Dimensions, with tolerances		
External dimensions:		[mm]
Size of utilizable area:		[mm]
Maximum thickness:		[mm]
Requirements		
Quantity:		[pcs]
Required delivery date:		
Are repeat orders to be expected?		[pcs/a]
Inquiry from:		

Application/problem	
Kind of radiation/source:	
Kind of detector:	
Optical arrangement	**Polarization state of radiation**
Angle of incidence:	☐ unpolarized
Angle of aperture:	☐ p-polarized
☐ photometric beam ☐ imaging beam	☐ s-polarized
Operating conditions	
Maximum operating temperature:	
Other operating conditions:	
Additional demands or wishes	
Quality documents	
Measurement documents:	☐ curve per lot ☐ label per filter (λ_c, HW, τ_{max})
☐ transmission ☐ reflection ☐ blocking (logarithmic)	
Other quality-documents:	

6. Questionnaire Anti-reflection coating

Please copy and enter your specific requirements.

Spectral values		
Antireflection in 1st passband	from λ_{D1} = to λ_{D2} =	[nm] [nm]
Reflection level in 1st passband	$\rho \leq$	[%]
Antireflection in 2nd passband	from λ_{D3} = to λ_{D4} =	[nm] [nm]
Reflection level in 2nd passband	$\rho \leq$	[%]

Operating conditions		
For laser applications:		
☐ CW ☐ pulsed laser	power:	[kW]
	pulse width:	
	repetition rate:	
	beam diameter:	
Desired LIDT:		[J/cm^2]
Maximum operating temperature:		

Quality documents	
Measurement documents:	☐ curve per lot ☐ curve per piece
Other quality documents:	

Special functions	
For scratch-resistant applications:	☐
Easy to clean top-coat:	☐

Dimensions, with tolerances		
External dimensions:	±	[mm]
Size of utilizable area:	±	[mm]
Lenses: radius of curvature	±	[mm]
(Center) thickness:	±	[mm]

Requirements	
Quantity:	[pcs]
Required delivery date:	
Are repeat orders to be expected?	[pcs/a]

Application/problem
Kind of radiation/source:
Kind of detector:

Optical arrangement	**Polarization state of radiation**
Angle of incidence:	☐ unpolarized
Angle of aperture:	☐ p-polarized
☐ photometric beam ☐ imaging beam Pixel-size:	☐ s-polarized

Additional demands or wishes
Inquiry from:

7. Questionnaire Mirror coating

Please copy and enter your specific requirements.

Spectral values			
1st reflection-band		from λ_{D1} = to λ_{D2} =	[nm] [nm]
Reflection level in 1st band		$\rho \geq$	[%]
2nd reflection-band		from λ_{D3} = to λ_{D4} =	[nm] [nm]
Reflection level in 2nd band		$\rho \geq$	[%]
Operating conditions			
For laser applications:			
☐ CW ☐ pulsed laser	power:		[kW]
	pulse width:		
	repetition rate:		
	beam diameter:		
Desired LIDT:			[J/cm^2]
Maximum operating temperature:			
Quality documents			
Measurement documents:		☐ curve per lot ☐ curve per piece	
Other quality documents:			
Dimensions, with tolerances			
External dimensions:		±	[mm]
Size of utilizable area:		±	[mm]
Thickness:		±	[mm]
Requirements			
Quantity:			[pcs]
Required delivery date:			
Are repeat orders to be expected?			[pcs/a]

Application/problem	
Kind of radiation/source:	
Kind of detector:	
Optical arrangement	**Polarization state of radiation**
Angle of incidence:	☐ unpolarized ☐ p-polarized ☐ s-polarized
Angle of aperture:	
☐ photometric beam ☐ imaging beam Pixel-size:	
Additional demands or wishes	
Inquiry from:	

8. Datasheets

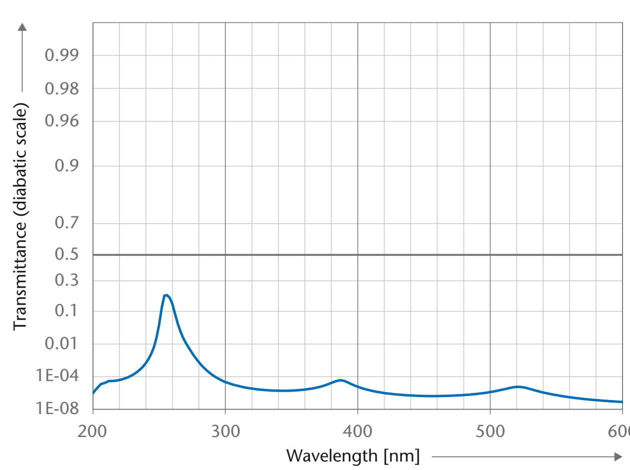
This chapter provides technical information of interference filters, special filters and coatings offered by SCHOTT Advanced Optics. A table for each filter type is displayed containing all relevant data. The shown graphics illustrate typical curves for overview purposes.

UV bandpass filter KMD 12

Spectral range 200 – 333 nm

λ_m-tolerance [% of λ_m]	+/– 0.5
Available with λ_m in range	200 – 333 nm
Spectral values	
HW (= FWHM) [nm]	9 – 13 (λ_m from 200 nm to 239 nm) 11 – 15 (λ_m from 240 nm to 333 nm)
τ_{max}	≥ 0.15 (λ_m from 195 nm to 239 nm) ≥ 0.18 (λ_m from 240 nm to 333 nm)
Q	approx. 1.8
q	approx. 5
Blocking range [nm]	unlimited
τ_{SM}	$\leq 10^{-5}$
Other properties	
Humidity resistance	MIL-Std-810C, method 507, proc. 1 : 5 cycles
Operating temperature	up to 70 °C for several hours up to 100 °C for short periods
Temperature dependency of λ_m : $\Delta\lambda_m/\Delta T$ [nm/K]	approx. +0.007
Notes	Filters delivered in mounts only Face filters with mirror side towards light source
Preferred dimensions [mm]	
External dimensions	Ø 12 +/– 0.15
Usable area	Ø ≥ 9
Thickness	4.75 +/– 0.1
Other dimensions upon request	

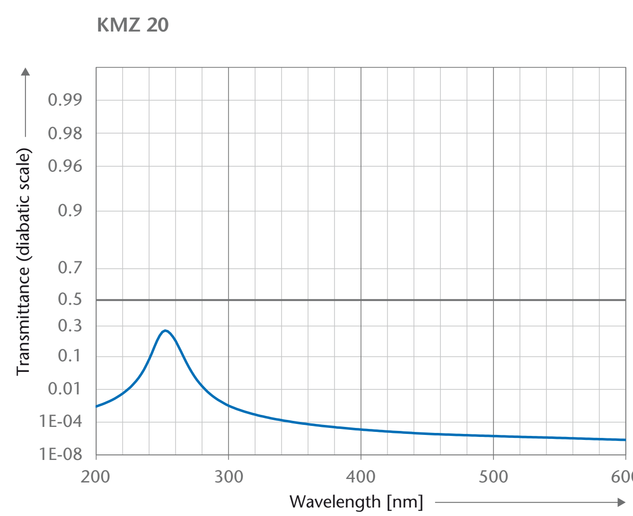
KMD 12



UV bandpass filter KMZ 20

Spectral range 200 – 333 nm

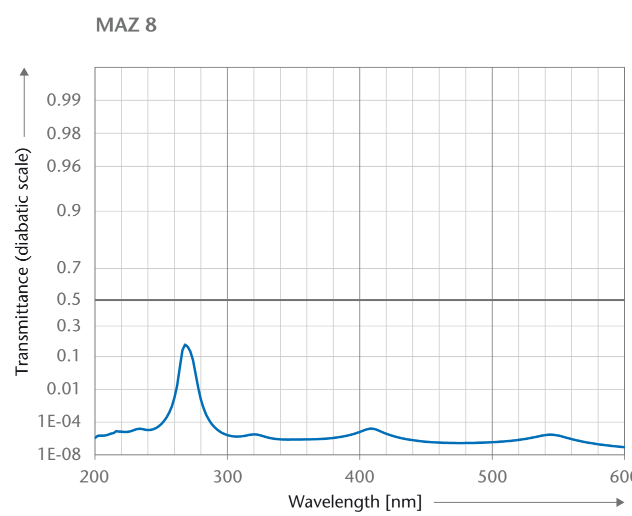
λ_m-tolerance [% of λ_m]	+/– 1.5
Available with λ_m in range	200 – 333 nm
Spectral values	
HW (= FWHM) [nm]	18 – 24
τ_{max}	≥ 0.20
Q	approx. 2.0
q	approx. 6.0
Blocking range [nm]	unlimited
τ_{SM}	$\leq 10^{-4}$
Other properties	
Humidity resistance	MIL-Std-810C, method 507, proc. 1 : 5 cycles
Operating temperature	up to 70 °C for several hours up to 100 °C for short periods
Temperature dependency of $\lambda_m : \Delta\lambda_m/\Delta T$ [nm/K]	approx. + 0.007
Notes	Filters delivered in mounts only Face filters with mirror side towards light source
Preferred dimensions [mm]	
External dimensions	Ø 12 +/– 0.15
Usable area	Ø ≥ 9
Thickness	4.75 +/– 0.1
Other dimensions upon request	



UV bandpass filter MAZ 8

Spectral range 220 – 333 nm

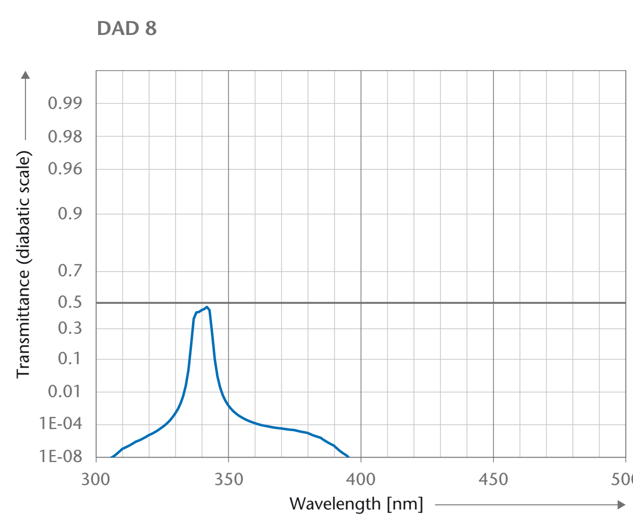
λ_m-tolerance [% of λ_m]	+/– 0.5
Available with λ_m in range	220 – 333 nm
Spectral values	
HW (= FWHM) [nm]	6 – 10
τ_{max}	≥ 0.15
Q	approx. 1.75
q	approx. 4.5
Blocking range [nm]	unlimited
τ_{SM}	≤ 10^{-5}
Other properties	
Humidity resistance	MIL-Std-810C, method 507, proc. 1 : 5 cycles
Operating temperature	up to 70 °C for several hours up to 100 °C for short periods
Temperature dependency of λ_m : $\Delta\lambda_m/\Delta T$ [nm/K]	approx. + 0.007
Notes	Filters delivered in mounts only Face filters with mirror side towards light source
Preferred dimensions [mm]	
External dimensions	Ø 12 +/– 0.15
Usable area	Ø ≥ 9
Thickness	4.75 +/– 0.1
Other dimensions upon request	



UV bandpass filter DAD 8

Spectral range 334 – 399 nm

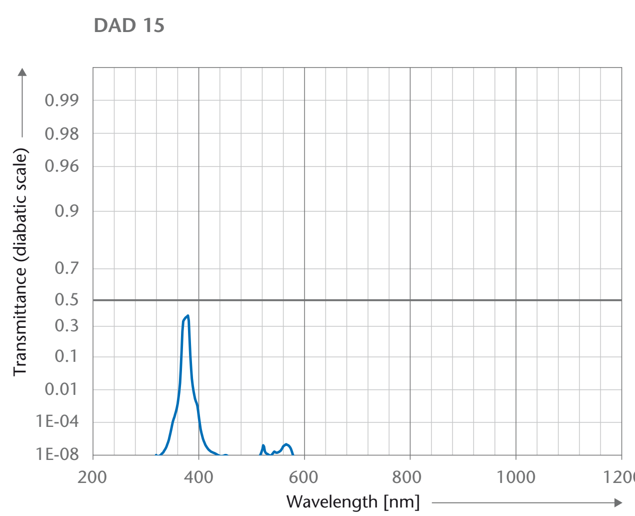
λ_m-tolerance [% of λ_m]	+/– 0.5
Available with λ_m in range	334 – 399 nm
Spectral values	
HW (= FWHM) [nm]	6 – 10
τ_{max}	≥ 0.30
Q	approx. 1.5
q	approx. 3.5
Blocking range [nm]	unlimited (λ_m from 334 nm to 360 nm) up to 1200 (λ_m from 361 nm to 399 nm)
τ_{SM}	≤ 10^{-5}
Other properties	
Humidity resistance	MIL-Std-810C, method 507, proc. 1 : 5 cycles
Operating temperature	up to 70 °C for several hours up to 100 °C for short periods
Temperature dependency of λ_m : $\Delta\lambda_m/\Delta T$ [nm/K]	approx. + 0.01
Notes	Unlimited blocking range on request, which can, however, change the filter specification
Preferred dimensions [mm]	
External dimensions	Ø 12 +/– 0.3
Usable area	Ø ≥ 9
External dimensions	Ø 25 +/– 0.3
Usable area	Ø ≥ 22
External dimensions	Ø 50 +/– 0.3
Usable area	Ø ≥ 47
Thickness	≤ 7
Other dimensions upon request	



UV bandpass filter DAD 15

Spectral range 334 – 399 nm

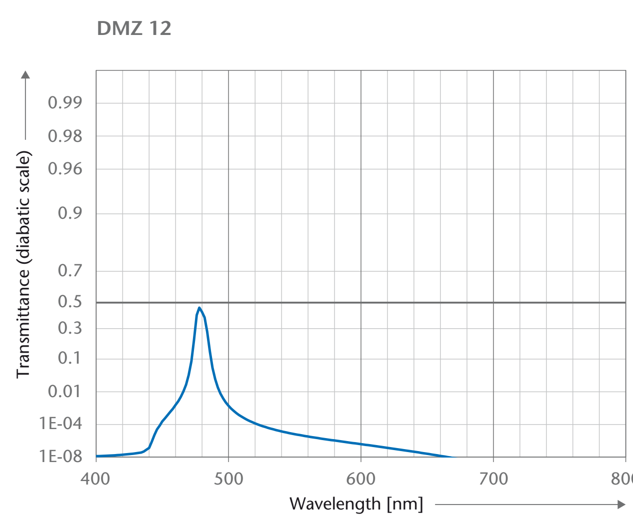
λ_m-tolerance [% of λ_m]	+/– 1.5
Available with λ_m in range	334 – 399 nm
Spectral values	
HW (= FWHM) [nm]	12 – 18
τ_{max}	≥ 0.30
Q	approx. 1.5
q	approx. 3.5
Blocking range [nm]	unlimited (λ_m from 334 nm to 360 nm) up to 1200 (λ_m from 361 nm to 399 nm)
τ_{SM}	$\leq 10^{-5}$
Other properties	
Humidity resistance	MIL-Std-810C, method 507, proc. 1 : 5 cycles
Operating temperature	up to 70 °C for several hours up to 100 °C for short periods
Temperature dependency of λ_m : $\Delta\lambda_m/\Delta T$ [nm/K]	approx. + 0.01
Notes	Unlimited blocking range on request, which can, however, change the filter specification
Preferred dimensions [mm]	
External dimensions	Ø 12 +/– 0.3
Usable area	Ø ≥ 9
External dimensions	Ø 25 +/– 0.3
Usable area	Ø ≥ 22
External dimensions	Ø 50 +/– 0.3
Usable area	Ø ≥ 47
Thickness	≤ 7
Other dimensions upon request	



VIS bandpass filter DMZ 12

Spectral range 400–599 nm

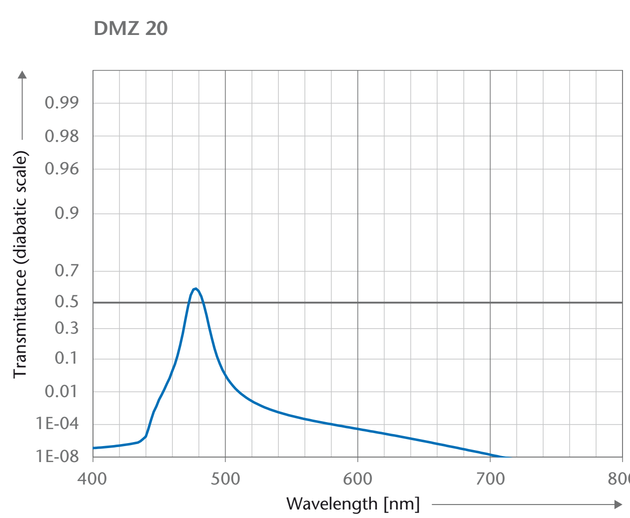
λ_m-tolerance [% of λ_m]	+/– 1.0
Available with λ_m in range	400–599 nm
Spectral values	
HW (= FWHM) [nm]	9–14
τ_{max}	≥ 0.35 (λ_m from 400 nm to 449 nm) ≥ 0.40 (λ_m from 450 nm to 599 nm)
Q	approx. 1.8
q	approx. 6
Blocking range [nm]	unlimited
τ_{SM}	$\leq 10^{-5}$
Other properties	
Humidity resistance	MIL-Std-810C, method 507, proc. 1 : 5 cycles
Operating temperature	up to 70 °C for several hours up to 100 °C for short periods
Temperature dependency of $\lambda_m : \Delta\lambda_m/\Delta T$ [nm/K]	approx. +0.02
Notes	Face filters with mirror side towards light source
Preferred dimensions [mm]	
External dimensions	Ø 12 +/– 0.3
Usable area	Ø ≥ 9
External dimensions	Ø 25 +/– 0.3
Usable area	Ø ≥ 22
External dimensions	Ø 50 +/– 0.3
Usable area	Ø ≥ 47
External dimensions	☐ 50 +/– 0.3
Usable area	☐ ≥ 47
Thickness	≤ 6
Other dimensions upon request	



VIS bandpass filter DMZ 20

Spectral range 400–599 nm

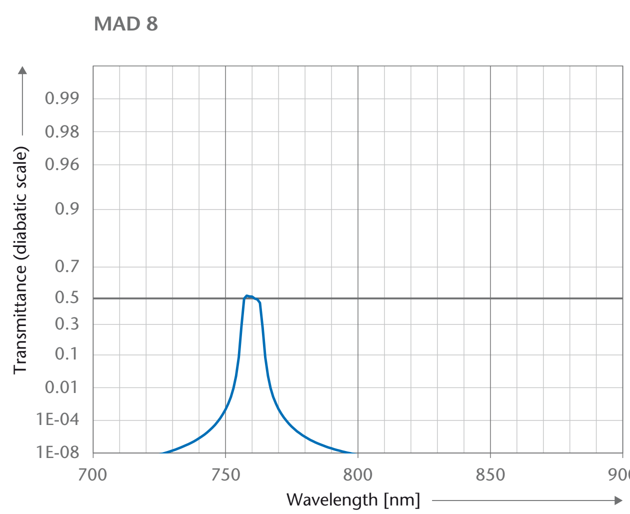
λ_m-tolerance [% of λ_m]	+/– 1.0
Available with λ_m in range	400–599 nm
Spectral values	
HW (= FWHM) [nm]	18–22
τ_{max}	≥ 0.45 (λ_m from 400 nm to 449 nm) ≥ 0.50 (λ_m from 450 nm to 599 nm)
Q	approx. 1.8
q	approx. 6
Blocking range [nm]	unlimited
τ_{SM}	≤ 10^{-5}
Other properties	
Humidity resistance	MIL-Std-810C, method 507, proc. 1 : 5 cycles
Operating temperature	up to 70 °C for several hours up to 100 °C for short periods
Temperature dependency of λ_m : $\Delta\lambda_m/\Delta T$ [nm/K]	approx. +0.02
Notes	Face filters with mirror side towards light source
Preferred dimensions [mm]	
External dimensions	Ø 12 +/– 0.3
Usable area	Ø ≥ 9
External dimensions	Ø 25 +/– 0.3
Usable area	Ø ≥ 22
External dimensions	Ø 50 +/– 0.3
Usable area	Ø ≥ 47
External dimensions	☐ 50 +/– 0.3
Usable area	☐ ≥ 47
Thickness	≤ 6
Other dimensions upon request	



VIS bandpass filter MAD 8

Spectral range 400 – 1100 nm

λ_m-tolerance [% of λ_m]	+/– 1.0
Available with λ_m in range	400 – 1100 nm
Spectral values	
HW (= FWHM) [nm]	6 – 12
τ_{max}	≥ 0.30 (λ_m from 400 nm to 429 nm) ≥ 0.45 (λ_m from 430 nm to 800 nm)
Q	approx. 1.5
q	approx. 3.0
Blocking range [nm]	unlimited
τ_{SM}	$\leq 10^{-5}$
Other properties	
Humidity resistance	MIL-Std-810C, method 507, proc. 1 : 5 cycles
Operating temperature	up to 70 °C for several hours up to 100 °C for short periods
Temperature dependency of λ_m : $\Delta\lambda_m/\Delta T$ [nm/K]	approx. + 0.02
Notes	Face filters with mirror side towards light source
Preferred dimensions [mm]	
External dimensions	Ø 12 +/– 0.3
Usable area	Ø ≥ 9
External dimensions	Ø 25 +/– 0.3
Usable area	Ø ≥ 22
External dimensions	Ø 50 +/– 0.3
Usable area	Ø ≥ 47
External dimensions	□ 50 +/– 0.3
Usable area	□ ≥ 47
Thickness	≤ 7
Other dimensions upon request	

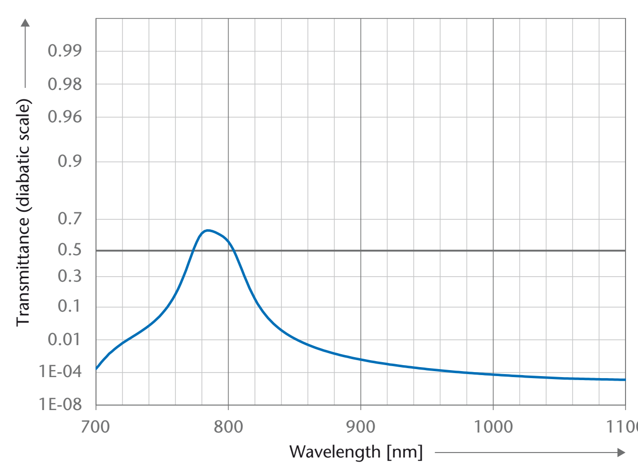


VIS bandpass filter KMZ 50

Spectral range 400 – 1400 nm

λ_m-tolerance [% of λ_m]	+/– 1.0
Available with λ_m in range	400 – 1400 nm
Spectral values	
HW (= FWHM) [nm]	30 – 60
τ_{max}	≥ 0.45 (λ_m from 400 nm to 449 nm) ≥ 0.55 (λ_m from 450 nm to 800 nm)
Q	approx. 1.8
q	approx. 6
Blocking range [nm]	unlimited
τ_{SM}	$\leq 10^{-5}$
Other properties	
Humidity resistance	MIL-Std-810C, method 507, proc. 1 : 5 cycles
Operating temperature	up to 70 °C for several hours up to 100 °C for short periods
Temperature dependency of λ_m : $\Delta\lambda_m/\Delta T$ [nm/K]	approx. +0.02
Notes	Face filters with mirror side towards light source
Preferred dimensions [mm]	
External dimensions	Ø 12 +/– 0.3
Usable area	Ø ≥ 9
External dimensions	Ø 25 +/– 0.3
Usable area	Ø ≥ 22
External dimensions	Ø 50 +/– 0.3
Usable area	Ø ≥ 47
External dimensions	□ 50 +/– 0.3
Usable area	□ ≥ 47
Thickness	≤ 4
Other dimensions upon request	

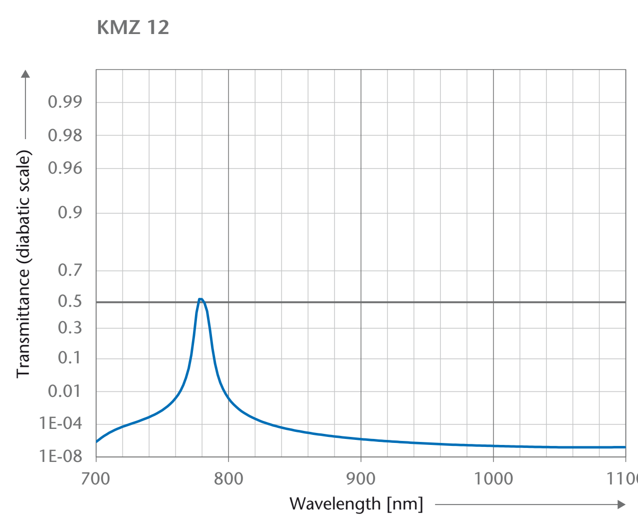
KMZ 50



VIS bandpass filter KMZ 12

Spectral range 600–800 nm

λ_m-tolerance [% of λ_m]	+/– 1.0
Available with λ_m in range	600–800 nm
Spectral values	
HW (= FWHM) [nm]	9–16
τ_{max}	≥ 0.40
Q	approx. 1.8
q	approx. 6
Blocking range [nm]	up to 2 · λ_m
τ_{SM}	≤ 10^{-5}
Other properties	
Humidity resistance	MIL-Std-810C, method 507, proc. 1 : 5 cycles
Operating temperature	up to 70 °C for several hours up to 100 °C for short periods
Temperature dependency of $\lambda_m : \Delta\lambda_m/\Delta T$ [nm/K]	approx. + 0.02
Notes	Unlimited blocking range on request, which can, however, change the filter specification Face filters with mirror side towards light source
Preferred dimensions [mm]	
External dimensions	Ø 12 +/– 0.3
Usable area	Ø ≥ 9
External dimensions	Ø 25 +/– 0.3
Usable area	Ø ≥ 22
External dimensions	Ø 50 +/– 0.3
Usable area	Ø ≥ 47
External dimensions	☐ 50 +/– 0.3
Usable area	☐ ≥ 47
Thickness	≤ 4
Other dimensions upon request	

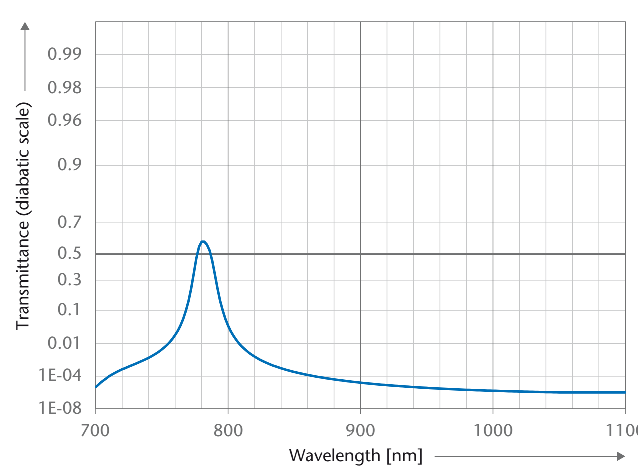


VIS bandpass filter KMZ 20

Spectral range 600–800 nm

λ_m-tolerance [% of λ_m]	+/– 1.0
Available with λ_m in range	600–800 nm
Spectral values	
HW (= FWHM) [nm]	18–24
τ_{max}	≥ 0.50
Q	approx. 1.8
q	approx. 6
Blocking range [nm]	up to $2 \cdot \lambda_m$
τ_{SM}	$\leq 10^{-5}$
Other properties	
Humidity resistance	MIL-Std-810C, method 507, proc. 1 : 5 cycles
Operating temperature	up to 70 °C for several hours up to 100 °C for short periods
Temperature dependency of λ_m : $\Delta\lambda_m/\Delta T$ [nm/K]	approx. +0.02
Notes	Unlimited blocking range on request, which can, however, change the filter specification Face filters with mirror side towards light source
Preferred dimensions [mm]	
External dimensions	Ø 12 +/– 0.3
Usable area	Ø ≥ 9
External dimensions	Ø 25 +/– 0.3
Usable area	Ø ≥ 22
External dimensions	Ø 50 +/– 0.3
Usable area	Ø ≥ 47
External dimensions	☐ 50 +/– 0.3
Usable area	☐ ≥ 47
Thickness	≤ 4
Other dimensions upon request	

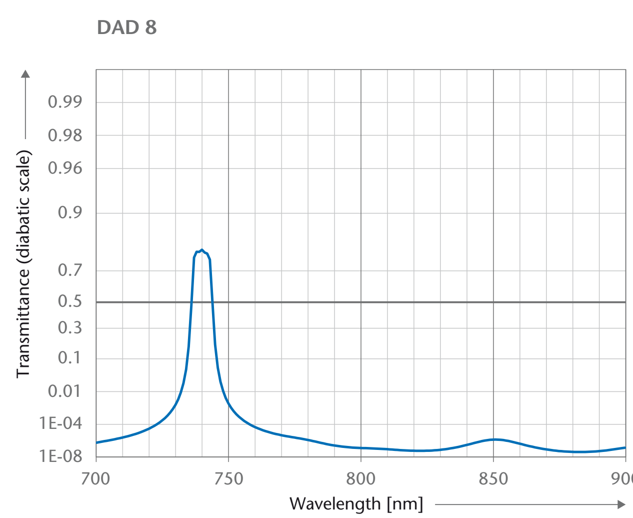
KMZ 20



VIS and near IR bandpass filter DAD 8

Spectral range 400–1100 nm

λ_m-tolerance [% of λ_m]	+/– 1.0
Available with λ_m in range	400–1100 nm
Spectral values	
HW (= FWHM) [nm]	6–10 (λ_m from 400 nm to 699 nm) 8–12 (λ_m from 700 nm to 1100 nm)
τ_{max}	≥ 0.40 (λ_m from 400 nm to 429 nm) ≥ 0.60 (λ_m from 430 nm to 479 nm) ≥ 0.65 (λ_m from 480 nm to 749 nm) ≥ 0.70 (λ_m from 750 nm to 1100 nm)
Q	approx. 1.5
q	approx. 3.5
Blocking range [nm]	up to 1200
τ_{SM}	$\leq 10^{-5}$
Other properties	
Humidity resistance	MIL-Std-810C, method 507, proc. 1 : 5 cycles
Operating temperature	up to 70 °C for several hours up to 100 °C for short periods
Temperature dependency of λ_m : $\Delta\lambda_m/\Delta T$ [nm/K]	approx. +0.02
Notes	
Preferred dimensions [mm]	
External dimensions	Ø 12 +/– 0.3
Usable area	Ø ≥ 9
External dimensions	Ø 25 +/– 0.3
Usable area	Ø ≥ 22
External dimensions	Ø 50 +/– 0.3
Usable area	Ø ≥ 47
External dimensions	□ 50 +/– 0.3
Usable area	□ ≥ 47
Thickness	≤ 7
Other dimensions upon request	

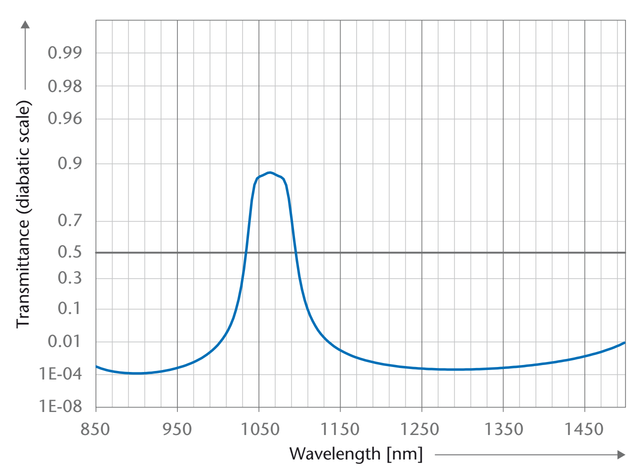


UV, VIS, and near IR bandpass filter DAD 8–70

Spectral range 300 – 1450 nm

Available with λ_m in range	300 – 1450 nm
Spectral values	
HW (= FWHM) [nm]	8 – 70
τ_{max}	For individual requirements concerning spectral values of λ_m, FWHM, transmittance within passband and blocking region, please contact us!
Q	
q	
Blocking range [nm]	
τ_{SM}	
Other properties	
Humidity resistance	MIL-Std-810C, method 507, proc. 1 : 10 cycles
Coating abrasion resistance	MIL-C-14806 A, para. 3.7
Coating adhesion	MIL-M-13508 C, para 4.4.6
Operating temperature (hard coating on single substrate)	up to approx. 350 °C
Operating temperature (if cemented mulitple substrates)	up to 70 °C for several hours up to 100 °C for short periods
Temperature dependency of λ_m : $\Delta\lambda_m/\Delta T$ [nm/K]	Can be optimized by a suitable choice of substrate and coating material combination to ≤ 0.005
Notes	Please indicate operating temperatures > 100 °C for an appropriate substrate selection
Preferred dimensions [mm]	
External dimensions	Ø 12 +/– 0.3
Usable area	Ø 12 +/– 0.3
External dimensions	Ø 25 +/– 0.3
Usable area	Ø 25 +/– 0.3
External dimensions	Ø 50 +/– 0.3
Usable area	Ø 50 +/– 0.3
External dimensions	☐ 50 +/– 0.3
Usable area	☐ 50 +/– 0.3
Thickness	1 +/– 0.2
Other dimensions upon request	

DAD 8–70



Linear variable (bandpass) filter VERIL

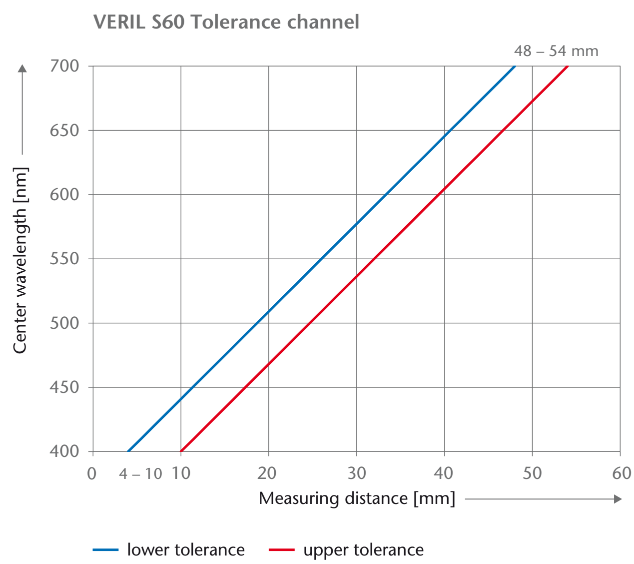
Spectral range 400 – 1000 nm

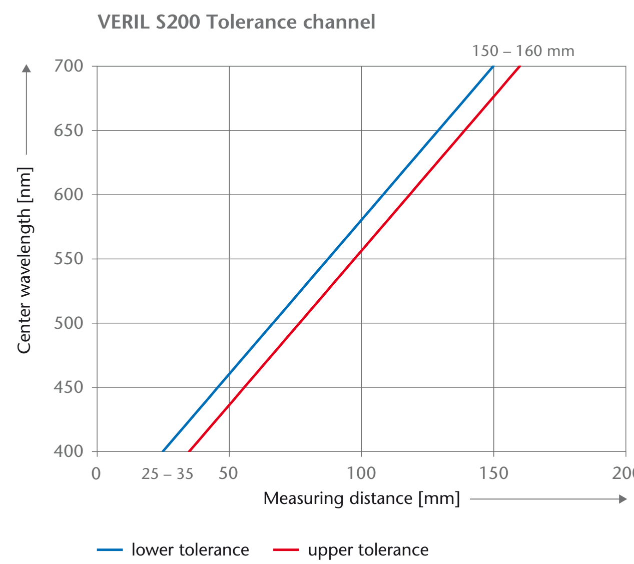
The spectral position of the center wavelength λ_m of the narrow passband of VERIL linear variable interference filters **changes constantly over the length of the filter**. These filters possess the same curve characteristics as the corresponding homogeneous filters. Additional blocking is achieved in some cases by graduated colored glasses (graduated optical filter glass).

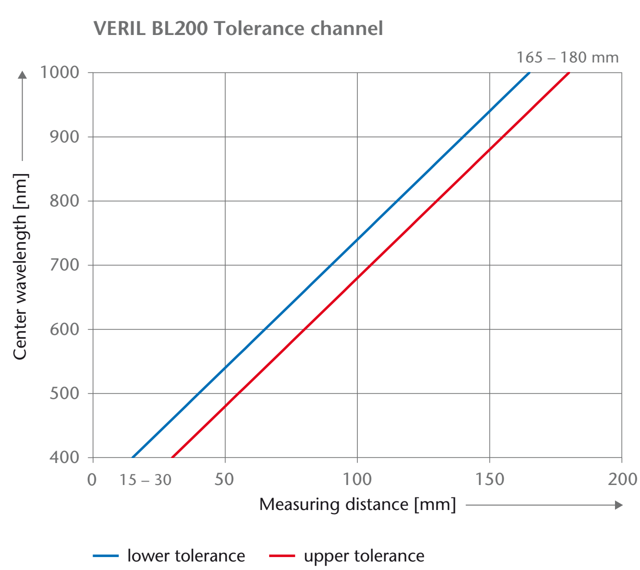
When linear variable filters with a pre-fitted slit are used, increasing the slit width widens the passband curve and reduces the maximum transmittance λ_{max}. Slit widths up to 1 mm in the case of VERIL S 60 filters and up to 3 mm in the case of VERIL S 200 and BL 200 have practically no effect on spectral performance.

The special method of manufacturing these filters gives rise to slight deviations in dispersion from filter to filter and to deviations in linearity. A calibration curve and a calibration table are included with each linear variable filter ordered.

Type	VERIL S 60	VERIL S 200	VERIL BL 200
Design analog	KMZ12	KMZ12	KMZ40
Available with λ_m in range	400 – 700 nm	400 – 700 nm	400 – 1000 nm
Spectrum length [nm]	38 – 50	115 – 135	135 – 165
Reciprocal linear dispersion [nm/mm]	6.0 – 7.9	2.2 – 2.6	3.6 – 4.4
Spectral values			
HW (= FWHM) [nm]	10 – 16 (λ_m = 450 nm) 10 – 15 (λ_m = 550 nm) 10 – 18 (λ_m = 650 nm)	10 – 16 (λ_m = 450 nm) 10 – 15 (λ_m = 550 nm) 10 – 18 (λ_m = 650 nm)	25 – 45 (λ_m = 500 nm) 35 – 50 (λ_m = 700 nm) 40 – 65 (λ_m = 900 nm)
τ_{max}	≥ 0.35 (λ_m = 450 nm) ≥ 0.45 (λ_m = 550 nm) ≥ 0.40 (λ_m = 650 nm)	≥ 0.35 (λ_m = 450 nm) ≥ 0.45 (λ_m = 550 nm) ≥ 0.40 (λ_m = 650 nm)	≥ 0.40 (λ_m = 500 nm) ≥ 0.40 (λ_m = 700 nm) ≥ 0.30 (λ_m = 900 nm)
Q	approx. 1.8	approx. 1.8	approx. 1.8
q	approx. 6	approx. 6	approx. 6
Blocking range [nm]	up to 2 · λ_m	up to 2 · λ_m	unlimited
τ_{SM}	≤ 10^{-4}	≤ 10^{-4}	≤ 10^{-4}
Other properties			
Humidity resistance	MIL-Std-810C, method 507, proc. 1 : 5 cycles	MIL-Std-810C, method 507, proc. 1 : 5 cycles	MIL-Std-810C, method 507, proc. 1 : 5 cycles
Operating temperature	up to 70 °C for several hours up to 100 °C for short periods	up to 70 °C for several hours up to 100 °C for short periods	up to 70 °C for several hours up to 100 °C for short periods
Notes	Unlimited blocking range on request, which can, however, change the filter specification Face filters with mirror side towards light source	Unlimited blocking range on request, which can, however, change the filter specification Face filters with mirror side towards light source	Face filters with mirror side towards light source
Preferred dimensions [mm]			
Length	60 + 0/– 0.3	200 + 0/– 0.3	200 + 0/– 0.3
Width	25 + 0/– 0.3	25 + 0/– 0.3	25 + 0/– 0.3
Thickness	≤ 5	≤ 6	≤ 6


VERIL S60 Tolerance channel
48 – 54 mm
Center wavelength [nm]
700
650
600
550
500
450
400
0
4 – 10
10
20
30
40
50
60
Measuring distance [mm]
lower tolerance
upper tolerance


VERIL S200 Tolerance channel
150 – 160 mm
Center wavelength [nm]
700
650
600
550
500
450
400
0
25 – 35
50
100
150
200
Measuring distance [mm]
lower tolerance
upper tolerance


VERIL BL200 Tolerance channel
165 – 180 mm
Center wavelength [nm]
1000
900
800
700
600
500
400
0
15 – 30
50
100
150
200
Measuring distance [mm]
lower tolerance
upper tolerance

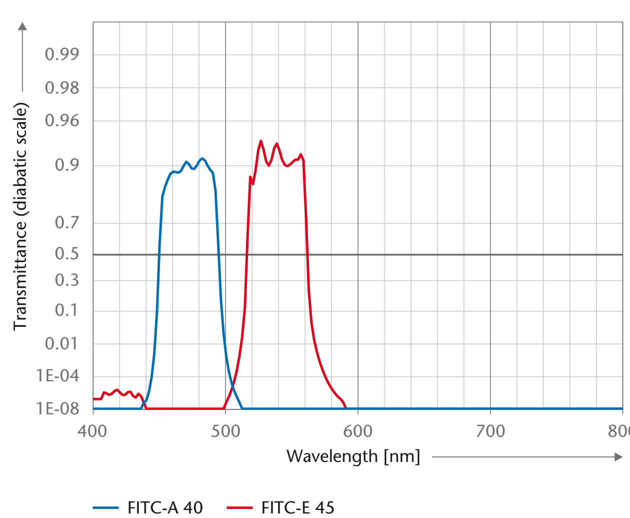
Fluorescence (bandpass) filters FITC A-40 and FITC E-45

These two filters are our standard filters for fluorescence microscopy or fluorescence spectroscopy. **Steeper filters are offered on customers' request.** If you need a steep filter please contact us.

Fluorochrome FITC (fluorescein-isothiocyanate) is used in fluorescence microscopy and spectroscopy for investigating immune reactions. These filters separate the absorbed light from the light source (FITC A-40) and the emitted light from the sample under investigation (FITC E-45).

Type	FITC A-40	FITC E-45
Spectral values		
Edge wavelengths λ_c ($\tau = 0.5$) [nm]	450 ± 5 492 ± 5	515 ± 5 560 ± 5
τ_D	0.75 (from 460 nm to 480 nm)	0.80 (from 530 nm to 550 nm)
τ_S	10^{-4} (below 430 nm) 10^{-4} (515 nm to 740 nm) 10^{-4} (740 nm to 850 nm)	10^{-5} (below 500 nm) 10^{-4} (600 nm to 700 nm)
Other properties		
Humidity resistance	MIL-Std-810C, method 507, proc. 1 : 5 cycles	MIL-Std-810C, method 507, proc. 1 : 5 cycles
Coating abrasion resistance	MIL-C-14806 A, para. 3.7	
Coating adhesion	MIL-M-13508 C, para 4.4.6	
Operating temperature	up to 70 °C for several hours up to 100 °C for short periods	up to 70 °C for several hours up to 100 °C for short periods
Temperature dependency of $\lambda_m : \Delta\lambda_m/\Delta T$ [nm/K]	approx. ≤ 0.005	approx. +0.02
Notes		
Preferred dimensions [mm]		
External dimensions	Ø 18 + 0/– 0.3	Ø 18 + 0/– 0.3
Usable area	Ø ≥ 16.5	Ø ≥ 16.5
External dimensions	Ø 25 + 0/– 0.3	Ø 25 + 0/– 0.3
Usable area	Ø ≥ 23.5	Ø ≥ 23.5
Thickness	≤ 3.5	≤ 3.5
Other dimensions upon request		

FITC A–E



“i-line” bandpass filter

Spectral range 365–400 nm

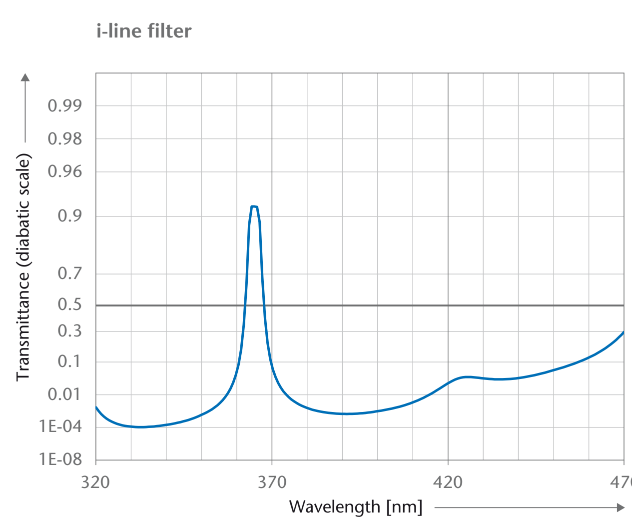
Accompanying optical glasses with high UV-transmittance at 365 nm (i-line wavelength) and high refractive index homogeneity, SCHOTT offers narrow bandpass filters for applications in i-line wafer steppers.

With the help of coating material development and high purity raw materials, SCHOTT is able to provide high transmission filters with extraordinary radiation resistance.

The requirements which are addressed to i-line interference filters are translated into a customized design. The filter is coated with various layers and this tailored multilayer system is characterized with an outstanding transmission at 365 nm combined with a narrow spectral bandwidth and very good homogeneity of the spectral behavior throughout the usable filter area.

Accompanied with long product life the obtained components are filters from SCHOTT, which are the materials of choice for various applications in the UV spectral region.

λ_m-tolerance [% of λ_m]	+/– 0.5
Available with λ_m in range	365–400 nm
Spectral values	
HW (= FWHM) [nm]	5–12
τ_{max}	≥ 0.85
Blocking range [nm]	unlimited
τ_{SM}	$\leq 10^{-5}$
Other properties	
Humidity resistance	MIL-Std-810C, method 507, proc. 1 : 5 cycles
Operating temperature	up to 70 °C for several hours up to 100 °C for short periods
Temperature dependency of $\lambda_m : \Delta\lambda_m/\Delta T$ [nm/K]	approx. + 0.007
Notes	Filters delivered in mounts only Face filters with mirror side towards light source
Preferred dimensions [mm]	
External dimensions	Ø 12 +/– 0.15
Usable area	Ø ≥ 9
Thickness	4.75 +/– 0.1
Other dimensions upon request	

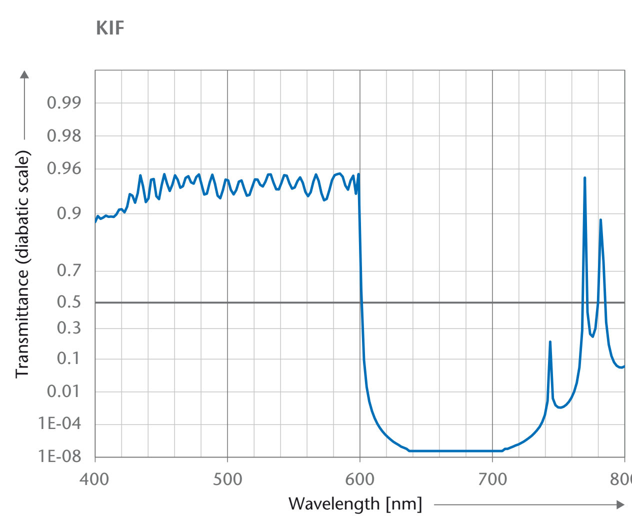


Shortpass filter KIF

Spectral range 300 – 1200 nm

These edge filters pass only the short wavelength and are made according to customers' specification for edge wavelengths between about 300 nm and 1200 nm.

Edge wavelength λ_c-tolerance [% of λ_c]	+/– 1.0 – 2.0
Available with edge wavelength λ_c (τ = 0.5) in range	300 – 1200 nm
Spectral values	
Slope $S_{\%}$ [%]	For individual requirements concerning spectral transmittance within passband and blocking region, please contact us!
τ_{max}	
τ_{DM}	
τ_{SM}	
Other properties	
Humidity resistance	MIL-Std-810C, method 507, proc. 1 : 10 cycles
Coating abrasion resistance	MIL-C-14806 A, para. 3.7
Coating adhesion	MIL-M-13508 C, para 4.4.6
Operating temperature	up to approx. 350 °C
Temperature dependency of λ_m : $\Delta\lambda_m/\Delta T$ [nm/K]	Can be optimized by a suitable choice of substrate and coating material combination to ≤ 0.005
Notes	Please indicate operating temperatures > 100 °C for an appropriate substrate selection
Preferred dimensions [mm]	
External dimensions	Ø 12 +/– 0.3
Usable area	Ø 12 +/– 0.3
External dimensions	Ø 25 +/– 0.3
Usable area	Ø 25 +/– 0.3
External dimensions	Ø 50 +/– 0.3
Usable area	Ø 50 +/– 0.3
External dimensions	☐ 50 +/– 0.3
Usable area	☐ 50 +/– 0.3
Thickness	1 +/– 0.2
Other dimensions upon request	

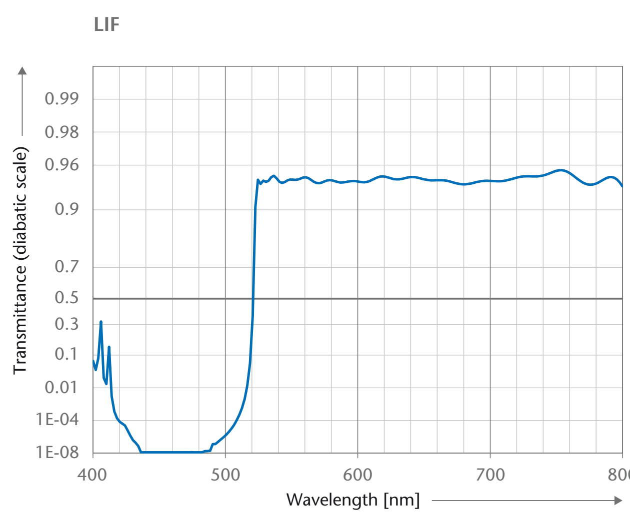


Longpass filter LIF

Spectral range 300 – 1200 nm

These edge filters pass only the long wavelength and are made according to customers' specification for edge wavelengths between about 300 nm and 1200 nm.

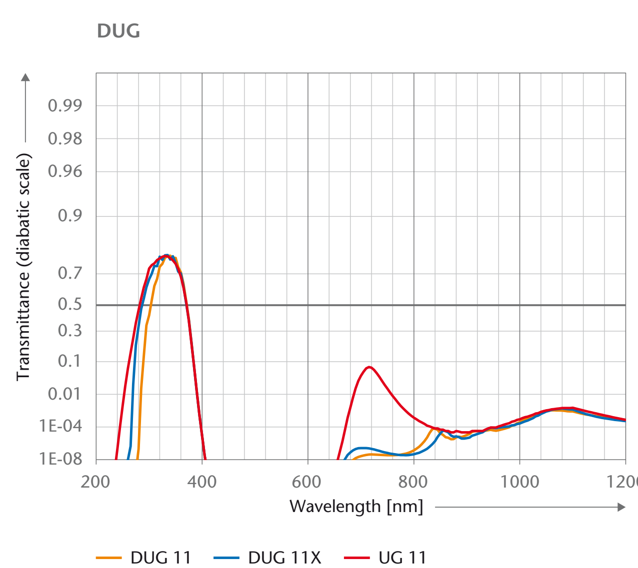
Edge wavelength λ_c-tolerance [% of λ_c]	+/– 1.0 – 2.0
Available with edge wavelength λ_c ($\tau = 0.5$) in range	300 – 1200 nm
Spectral values	
Slope $S_{\%}$ [%]	For individual requirements concerning spectral transmittance within passband and blocking region, please contact us!
τ_{max}	
τ_{DM}	
τ_{SM}	
Other properties	
Humidity resistance	MIL-Std-810C, method 507, proc. 1 : 10 cycles
Coating abrasion resistance	MIL-C-14806 A, para. 3.7
Coating adhesion	MIL-M-13508 C, para 4.4.6
Operating temperature	up to approx. 350 °C
Temperature dependency of λ_m : $\Delta\lambda_m/\Delta T$ [nm/K]	Can be optimized by a suitable choice of substrate and coating material combination to ≤ 0.005
Notes	Please indicate operating temperatures > 100 °C for an appropriate substrate selection
Preferred dimensions [mm]	
External dimensions	Ø 12 +/– 0.3
Usable area	Ø 12 +/– 0.3
External dimensions	Ø 25 +/– 0.3
Usable area	Ø 25 +/– 0.3
External dimensions	Ø 50 +/– 0.3
Usable area	Ø 50 +/– 0.3
External dimensions	☐ 50 +/– 0.3
Usable area	☐ 50 +/– 0.3
Thickness	1 +/– 0.2
Other dimensions upon request	



UV bandpass filters DUG 11 and DUG 11X (combination with filter glass)

The UV-broadband filter types DUG 11 & DUG 11 X are made of SCHOTT UV-transmitting optical filter glass of the type UG 11, whereby its typical secondary passband at about 720 nm has been blocked by an additional coating on both sides. These coating layers also work as a **protective coating** against external influences. The types DUG 11 and DUG 11 X, in contrast to pure UG 11 filter glass, are much **more stable** with regard to **intensive shortwave UV-radiation** (solarization resistance), as the layer systems absorb or reflect this radiation to a greater extent and hence prevent it from penetrating into the filter glass.

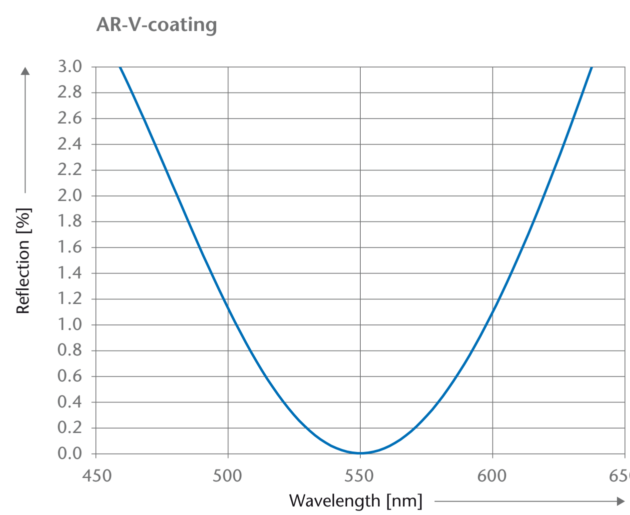
Type	DUG 11	DUG 11 X
Center wavelength λ_m [nm]	approx. 340	approx. 320
Spectral values		
HW (= FWHM) [nm]	approx. 70	approx. 100
τ_{max}	≥ 0.70	≥ 0.70
Q	approx. 1.3	approx. 1.3
q	approx. 1.6	approx. 1.6
τ_{SM}	$\leq 10^{-5}$ (below 260 nm) $\leq 10^{-8}$ (420nm to 649nm) $\leq 5 \cdot 10^{-6}$ (650 nm to 799 nm) $\leq 5 \cdot 10^{-4}$ (800 nm to 999 nm) $\leq 5 \cdot 10^{-3}$ (1000 nm to 1200 nm)	$\leq 10^{-5}$ (below 260 nm) $\leq 10^{-8}$ (420nm to 649nm) $\leq 5 \cdot 10^{-6}$ (650 nm to 799 nm) $\leq 5 \cdot 10^{-4}$ (800 nm to 999 nm) $\leq 5 \cdot 10^{-3}$ (1000 nm to 1200 nm)
Other properties		
Humidity resistance	MIL-Std-810C, method 507, proc. 1 : 10 cycles	MIL-Std-810C, method 507, proc. 1 : 10 cycles
Coating abrasion resistance	MIL-C-14806 A, para. 3.7	MIL-C-14806 A, para. 3.8
Coating adhesion	MIL-M-13508 C, para 4.4.6	MIL-M-13508 C, para 4.4.6
Operating temperature	up to approx. 220 °C	up to approx. 220 °C
Notes	Please indicate operating temperatures > 100 °C for appropriate measures for minimizing breakage risk	Please indicate operating temperatures > 100 °C for appropriate measures for minimizing breakage risk
Preferred dimensions [mm]		
External dimensions	☐ 50 + 0/– 0.3	☐ 50 + 0/– 0.3
Usable area	☐ ≥ 46	☐ ≥ 46
Thickness	2.0 +/– 0.2	2.0 +/– 0.2
Other dimensions on request		
Thickness changes lead to transmittance changes		



AR coating AR-V-coating

Spectral range 200–25000 nm

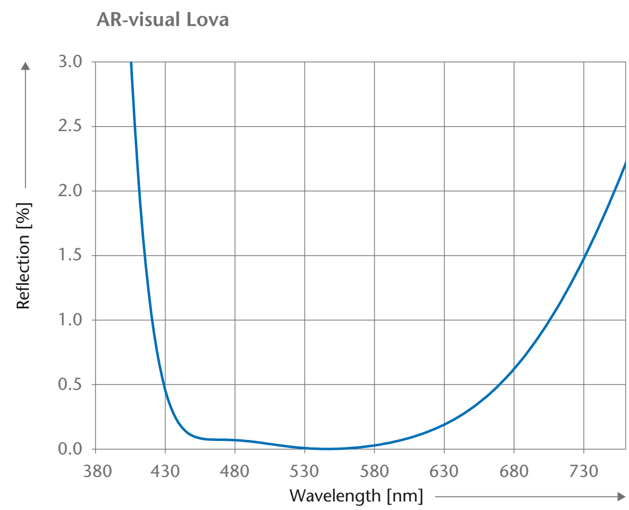
Center wavelength-tolerance [%]	+/– 0.5
Available with center wavelength in range	200–25000 nm
Spectral values	
Reflectance ρ at center wavelength	< 0.2 %
Other properties	
Humidity resistance	MIL-Std-810C, method 507, proc. 1 : 5 cycles
Coating abrasion resistance	MIL-C-14806 A, para. 3.7
Coating adhesion	MIL-M-13508 C, para 4.4.6
Operating temperature	up to 250 °C for several hours
Notes	
Preferred dimensions [mm]	
External dimensions	up to 590 x 730 mm
Usable area	upon request
Thickness	upon request
Other dimensions upon request	



AR coating AR-VIS Lova

Spectral range 350 – 1000 nm

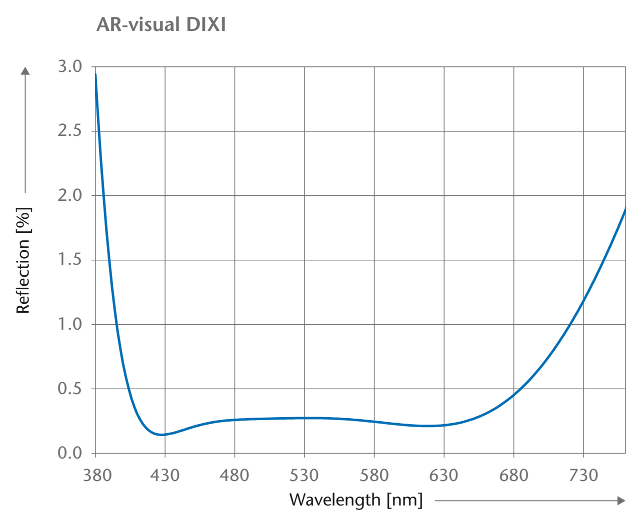
Coating materials	metaloxide + MgF_2
Available performance shifted in range	350 – 1000 nm
Spectral values	
Reflectance ρ	440 – 650 nm < 0.5 % average
Other properties	
Humidity resistance	MIL-Std-810C, method 507, proc. 1 : 10 cycles
Coating abrasion resistance	MIL-C-675 C, para. 4.5.10
Coating adhesion	MIL-M-13508 C, para 4.4.6
Operating temperature	up to 250 °C for several hours
Notes	
Preferred dimensions [mm]	
External dimensions	up to Ø 200 mm
Usable area	upon request
Thickness	upon request
Other dimensions upon request	



AR coating AR-VIS DIXI

Spectral range 350 – 1000 nm

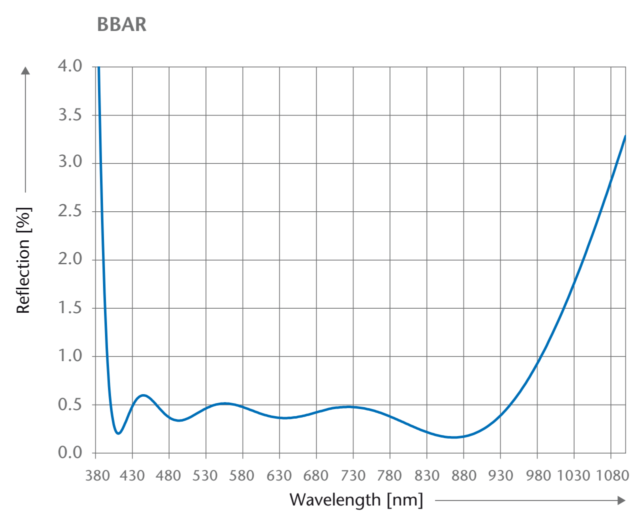
Coating materials	hard metal oxide
Available performance shifted in range	350 – 1000 nm
Spectral values	
Reflectance ρ	420 – 680 nm < 0.8 % average
Other properties	
Humidity resistance	MIL-Std-810C, method 507, proc. 1 : 10 cycles
Coating abrasion resistance	MIL-C-14806 A, para. 3.7
Coating adhesion	MIL-M-13508 C, para 4.4.6
Operating temperature	up to 250 °C for several hours
Notes	
Preferred dimensions [mm]	
External dimensions	
Usable area	upon request
Thickness	upon request
Other dimensions upon request	



AR coating Broadband AR-coating

Spectral range 350 – 1000 nm

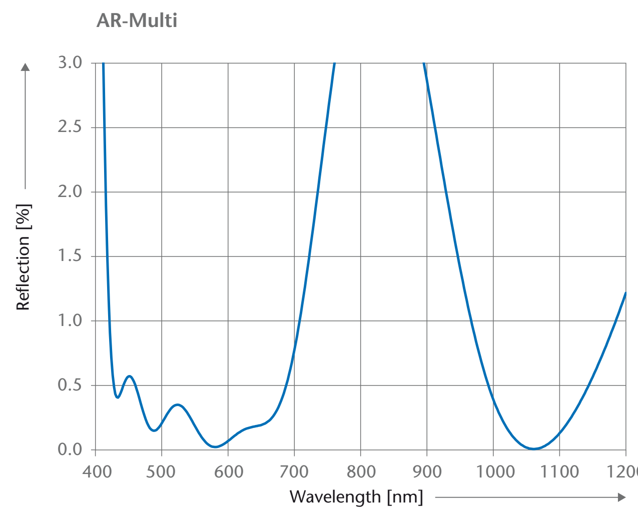
Coating materials	metaloxide + MgF_2
Available performance shifted in range	350 – 1000 nm
Spectral values	
Reflectance ρ	400 – 450 nm < 3 % 450 – 1000 nm < 1.3 % 1000 – 1100 nm < 3.5 %
Other properties	
Humidity resistance	MIL-Std-810C, method 507, proc. 1 : 10 cycles
Coating abrasion resistance	MIL-C-675 C, para. 4.5.10
Coating adhesion	MIL-M-13508 C, para 4.4.6
Operating temperature	up to 250 °C
Notes	
Preferred dimensions [mm]	
External dimensions	up to Ø 200 mm
Usable area	upon request
Thickness	upon request
Other dimensions upon request	



AR coating Multiband AR-coating

Spectral range 350 – 1600 nm

Coating materials	metaloxide + MgF_2
Available performance shifted in range	350 – 1600 nm
Spectral values	
Reflectance ρ	450 – 650 nm < 1 % average 1064 nm < 1 %
Other properties	
Humidity resistance	MIL-Std-810C, method 507, proc. 1 : 10 cycles
Coating abrasion resistance	MIL-C-675 C, para. 4.5.10
Coating adhesion	MIL-M-13508 C, para 4.4.6
Operating temperature	up to 250 °C
Notes	
Preferred dimensions [mm]	
External dimensions	up to Ø 200 mm
Usable area	upon request
Thickness	upon request
Other dimensions upon request	



VIS scratch-resistant (hard) AR coating

Spectral range 450 – 700 nm

SCHOTT offers a variety of customized glass products with a special hard coating in reliable and reproducible quality. Using magnetron sputtering and our own proprietary process for hard AR coatings results in both scratch resistance and AR characteristics (also for different angle of incidence possible).

Dimensions

- Up to 590 x 730 mm and thickness < 40 mm

Proof of scratch resistance

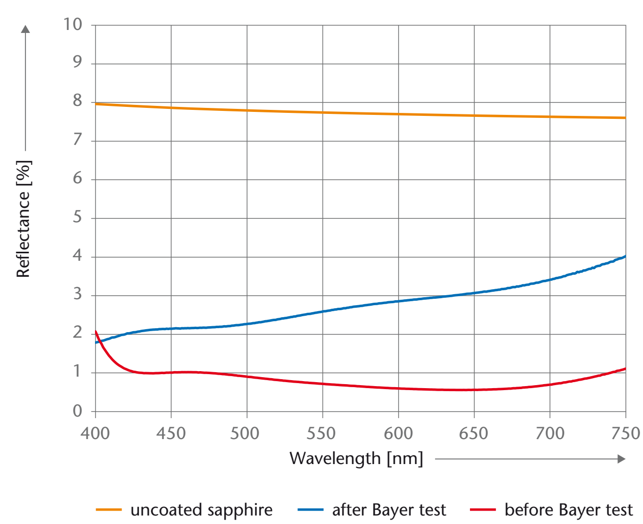
Scratch resistance is often measured after performing the so-called Bayer test (often as variation of the original test in ASTM F735) where the hard AR-coated substrate is covered by sand and oscillates many thousand of times with several hundred rounds per minute. The optical performance (e. g. reflection) is measured before and after the Bayer abrasion test.

The graph below shows the result of a sapphire sample substrate (with about 8 % reflection if uncoated) with the following specifications:

- Hard coated AR for 450 nm to 700 nm
- Reflection < 1.5 % @ 450 nm … 700 nm before abrasion test
- Reflection < 5 % @ 450 nm … 700 nm after abrasion test

Example specification	
Available wavelength range [nm]	450 – 700
Substrate	sapphire
Reflectance uncoated substrate	approx. 8 %
Reflectance before abrasion test (450 nm – 700 nm)	< 1.5 %
Reflectance after abrasion test (450 nm – 700 nm)	< 5 %
Other properties	
Scratch resistance	according Bayer test (as variation of the original test in ASTM F735)
Notes	other substrates on request
Preferred dimensions [mm]	
External dimensions	up to 590 x 730 mm
Usable area	
Thickness	< 40
Other dimensions upon request	

Reflectance of sapphire

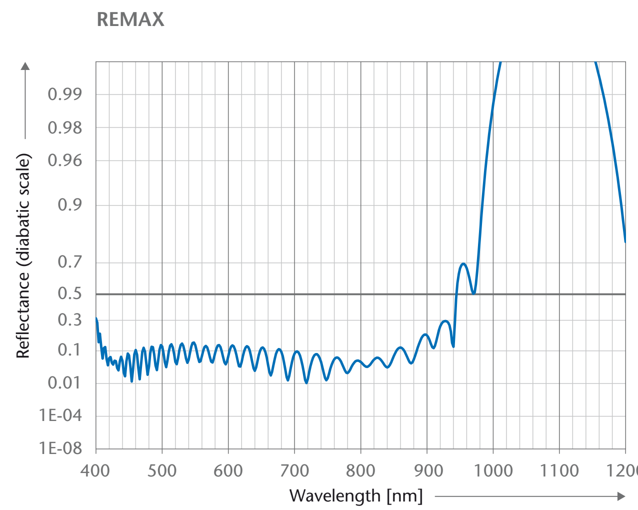


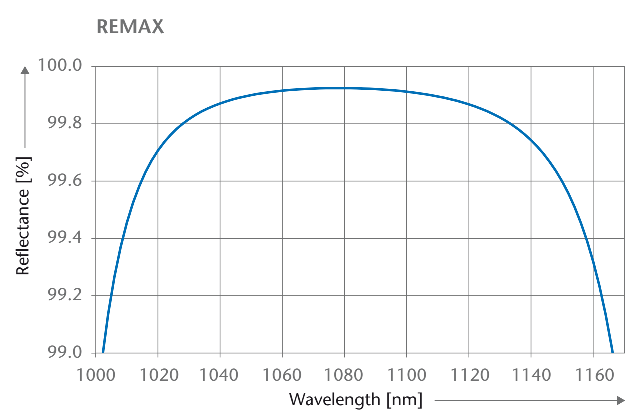
Dielectric (laser) mirror REMAX

Spectral range 300 – 2500 nm

Mirrors of this type consist of dielectric layers with low absorption and are therefore suited for laser applications.

Spectral range	300 – 2500 nm
Type	REMAX
Reflectance ρ	1064 nm < 99.8 % higher reflectivities on request
Other properties	
Humidity resistance	MIL-Std-810C, method 507, proc. 1 : 5 cycles
Operating temperature	up to 200 °C
Notes	typical application cw-laser power > 50 kW
Preferred dimensions [mm]	
External dimensions	up to Ø 200 mm
Usable area	
Thickness	upon request
Other dimensions upon request	

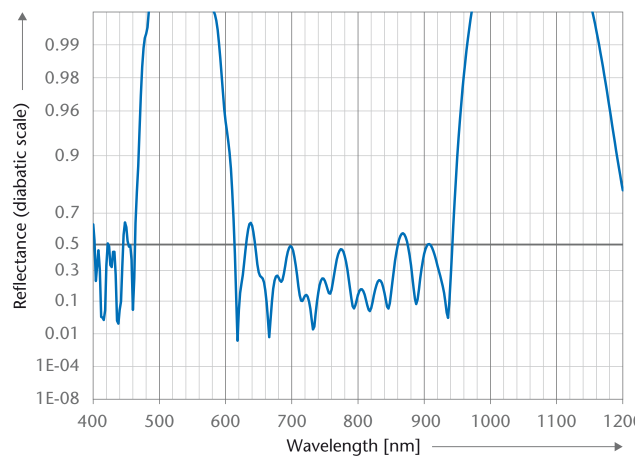




Dielectric (laser) mirror REMAX 2 band

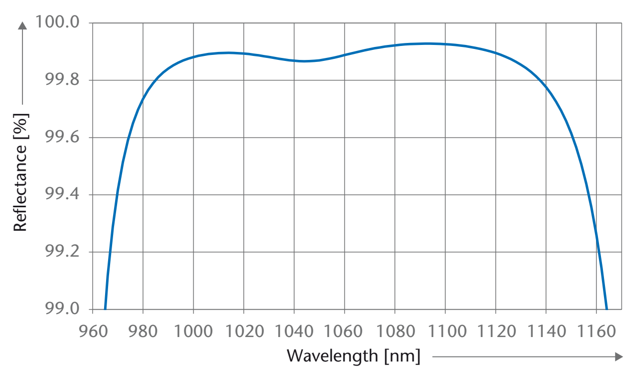
Spectral range 300–2500 nm

REMAX 2 band



Reflectance ρ	1064 nm < 99.8 % higher reflectivities on request
Other properties	
Humidity resistance	MIL-Std-810C, method 507, proc. 1 : 5 cycles
Operating temperature	up to 200 °C
Notes	typical application cw-laser power > 50 kW
Preferred dimensions [mm]	
External dimensions	up to Ø 200 mm
Usable area	
Thickness	upon request
Other dimensions upon request	

REMAX 2 band

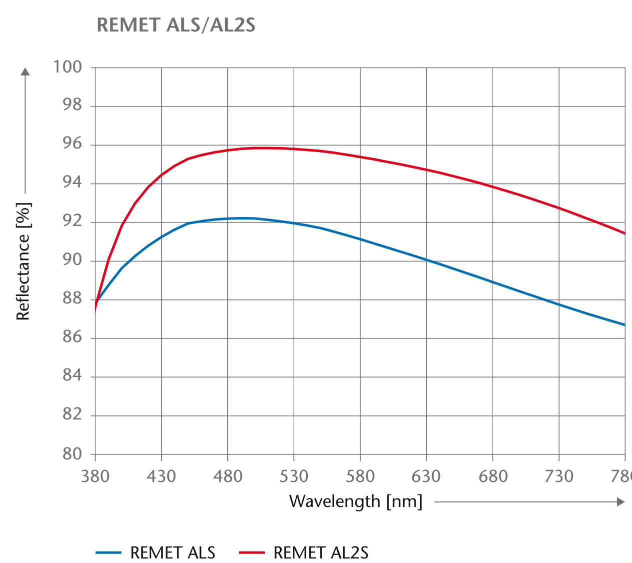


Metallic mirrors REMET ALS

Spectral range 400–800 nm

Mirrors of this type consist of a metallic layer and if needed with a SiO_2 protective layer.

Angle of incidence	0–45°
Available in wavelength range	400–800 nm
Available article variants	
Protected Aluminum mirror:	REMET ALS
Dielectric enhanced Aluminum mirror	REMET AL2S
Reflectance	
REMET ALS: reflectance ρ	400–700 nm > 85 % average
REMET AL2S: reflectance ρ	400–700 nm > 90 % average
Other properties	
Adhesion	DIN 58196 – K1
Rubbing test	DIN 58196 – H25
Operating temperature	up to 70 °C for several hours up to 100 °C for short periods
Notes	
Preferred dimensions [mm]	
External dimensions	up to Ø 300 mm
Thickness	upon request
Other dimensions upon request	



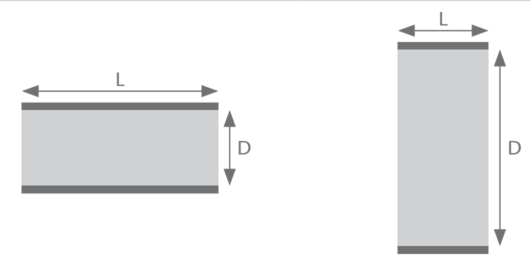
Transparent conducting oxide coating (TCO)

Spectral range 400 – 5000 nm

A transparent conducting coating (TCO) ensures both electrical conductivity and optically transparency. SCHOTT uses ITO (indium-tin-oxide) for this purpose.

Transparent conductive oxides (TCO) combine transparency in the visible spectrum, infrared reflectivity and electrical conductivity. Indium Tin Oxide (In2O3:Sn) is the most common.	
Available article variants	
	ITO single layer ITO with AR coating ITO with AR coating and flexible connectors structured ITO for touch screens
Optical sheet resistance can be adapted:	7 – 5000 Ω/square
Typical sheet resistances/ tolerances	10+/–4 Ω/square 100+/–10 Ω/square 300+/–30 Ω/square
Reflectance ρ	
Reflection if AR-coating is applied on top of ITO:	450 – 650 nm < 1 % average other ranges on request
Other properties	
Humidity resistance	MIL-Std-810C, method 507, proc. 1 : 10 cycles
Operating temperature	up to 200 °C for several hours
Notes	Flexible connectors can be applied by conductive epoxy
Preferred dimensions [mm]	
External dimensions	up to 590 x 730 mm (sputtering) up to 150 x 150 mm (EB)
Usable area	upon request
Thickness	upon request
Other dimensions on request	
Sheet resistance (Rs) is specified for transparent conductive thin films. The spectral transmission/reflection and electrical conductivity depend on TCO-material and coating thickness.	
$Rs = \frac{\text{Resistivity}}{\text{filmthickness}}$ [Ω/square] no units of area!	
Resistivity ρ is a property of bulk material – sheet resistance is a property of thin films for example: $\rho = 3 \times 10^{-4}$ Ω cm, film thickness 300 nm, then Rs = 10 Ω/square	

If a voltage is applied to electrodes on opposites edges of the film, the resistance Re is given by the length L and the distance D of the electrodes and the sheet resistance:

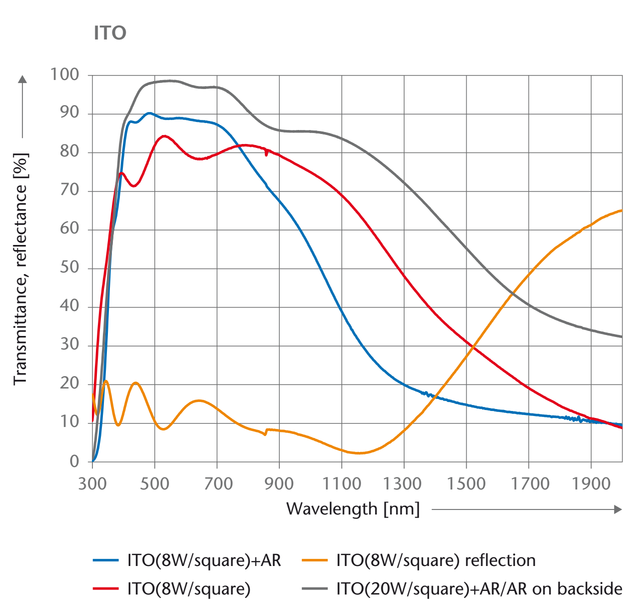


example: Rs = 10 Ω/sq and L = 5 x D

$$R_e = 10\ \Omega/\text{sq.x}\ \frac{D}{L} = 2\ \Omega$$

example: Rs = 10 Ω/sq and L = D/5

$$R_e = 10\ \Omega/\text{sq.x}\ \frac{D}{L} = 50\ \Omega$$

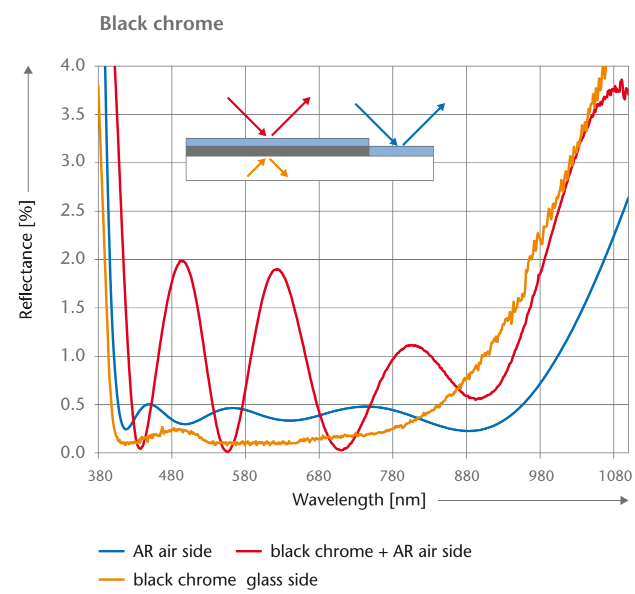


Black chrome coating for light absorption

Spectral range 400 – 1000 nm

This coating absorbs light and can be used for masking.

Available with λ_m in range	400 – 1000 nm
Substrate materials	Glass, fused silica
Spectral values	
Reflectance ρ (incidence from air side)	420 – 1000 nm < 3 % average
Optical density	> 3.5
Other properties	
Operating temperature	up to 300 °C for several hours
Humidity resistance	MIL-Std-810C, method 507, proc. 1 : 10 cycles
Coating abrasion resistance	MIL-C-14806 A, para. 3.7
Coating adhesion	MIL-M-13508 C, para 4.4.6
Notes	
External dimensions	up to 150 x 150 mm (EB)
Usable area	upon request
Thickness	upon request
Other dimensions on request	



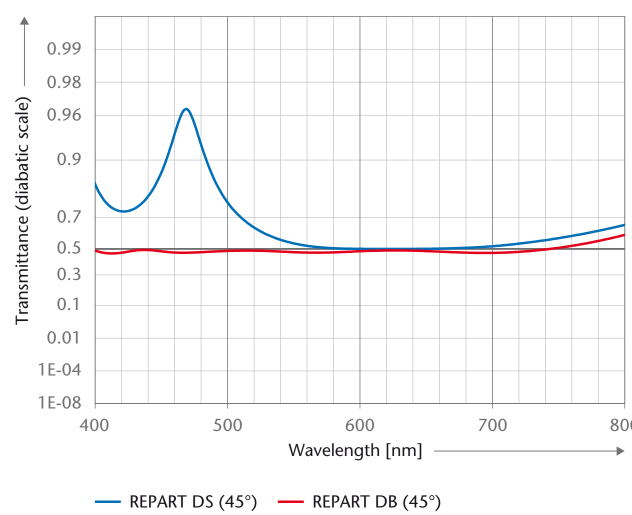
Dielectric beam splitter coating REPART

Spectral range 400–1000 nm

Splitting light (power) with different splitting ratio and optimized for a single wavelength or a broad wavelength band can be offered.

Available article variants	
REPART DB	R (450–650) = 50 % ± 6 % (a.o.i. 45°)
REPART DS	T(650) = 50 % ± 5 % (a.o.i. 45°)
Other properties	
Humidity resistance	MIL-Std-810C, method 507, proc. 1 : 10 cycles
Operating temperature	up to 250 °C for several hours
Temperature dependency of λ_m : $\Delta\lambda_m/\Delta T$ [nm/K]	approx. +0.007
Notes	
Preferred dimensions [mm]	
External dimensions	up to 150 x 150 mm
Usable area	upon request
Thickness	upon request
Other dimensions upon request	

Repart (oblique incidence)



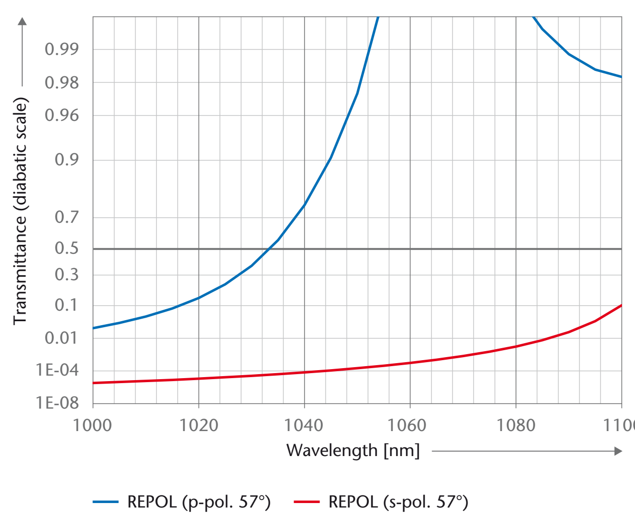
Polarization beam splitter coating

Spectral range 300 – 2500 nm

Here the s-polarization (TE polarization) and the p-polariza-tion (TM polarization) are separated from each other at a specific wavelength. The polarization beam splitter plate must be aligned under an angle of 45°.

Type	REPOL
Available article variants	
REPOL (e.g. 1064 nm)	Tp(1064 nm) > 97 %
	Ts(1064) < 1 %
	a.o.i. = 57°±2°
Other properties	
Humidity resistance	MIL-Std-810C, method 507, proc. 1 : 10 cycles
Operating temperature	up to 250 °C for several hours
Temperature dependency of λ_m : $\Delta\lambda_m/\Delta T$ [nm/K]	approx. +0.007
Notes	
Polarizing beamsplitters are available in a broad range of wavelengths and can be adapted to different angles of oblique incidence.	
Preferred dimensions [mm]	
External dimensions	ca. 60 x 60 mm
Usable area	upon request
Thickness	upon request
Other dimensions upon request	

REPOL (Brewster angle 57°)



Notch (up to triple notch) filter

Spectral range 400 – 2000 nm

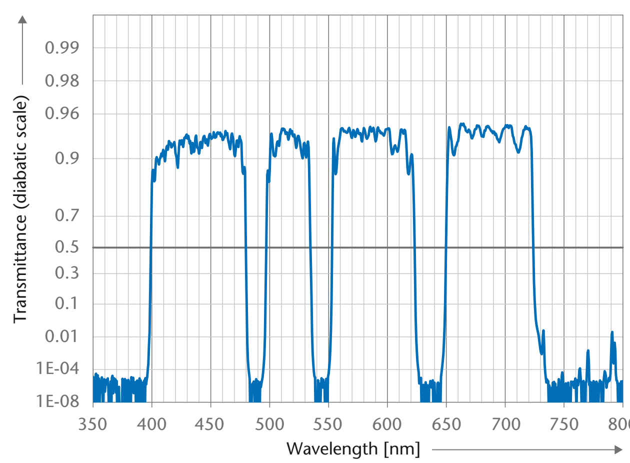
Notch filters provide versatile solutions concerning half widths, center wavelengths and blocking properties typically needed in Raman spectroscopy, fluorescence excitation and emission in bio-photonic, medical analytical, chemical, forensic, and pharmaceutical applications.

SCHOTT offers steep notch wavelengths and high blocking at selectable wavelengths. Highly selective notch wavelengths can be adapted to the customer's specifications. Designs can range from single notch to triple notch.

This type of filter is made according to customers' specification. An example specification for a triple notch filter is as follows:

Notch wavelength λ_S	400 – 2000 nm
Spectral values	
τ_{ave}	≥ 0.90
τ_{SM}	$\leq 10^{-5}$
Other properties	
Humidity resistance	MIL-Std-810C, method 507, proc. 1 : 10 cycles
Operating temperature	up to approx. 350 °C
Notes	All specs per customers' request
Preferred dimensions [mm]	
External dimensions	Ø < 25
Usable area	Ø < 24
Thickness	≤ 5
Other dimensions upon request	

Example of a triple notch filter (no backside AR)



9. Optical filters for color and brightness measurements: SFK 100A, SFK 101B, SFK 102A

Color measurements using the tristimulus method

The measurement of color using the tristimulus method is described by German Industrial Standard DIN 5033, part 6. Color stimulus by measuring the three tristimulus values may be achieved by means of a photometer if the radiation detector's sensitivity is adjusted to definite spectral valuation functions with the aid of appropriate optical filters. If the measurement results are expected to directly provide the tristimulus values within the CIE 1931 standard colorimetric system, the precision filters' spectral transmission factors $\tau_x(\lambda)$, $\tau_y(\lambda)$ and $\tau_z(\lambda)$ have to meet the requirements given by:

$$\tau_x(\lambda) = \frac{c_x \cdot \bar{x}(\lambda)}{S_1(\lambda)},\ \tau_y(\lambda) = \frac{c_y \cdot \bar{y}(\lambda)}{S_2(\lambda)},\ \tau_z(\lambda) = \frac{c_z \cdot \bar{z}(\lambda)}{S_3(\lambda)}$$

where $\bar{x}(\lambda)$, $\bar{y}(\lambda)$, and $\bar{z}(\lambda)$ are the color-matching functions for the CIE 1931 standard colorimetric observer (see Fig. 1), and where $S_1(\lambda)$, $S_2(\lambda)$, and $S_3(\lambda)$ are the spectral sensitivities of the detectors receiving the non-filtered radiation, and where c_x, c_y, and c_z are wavelength-independent instrument constants that can be determined empirically.

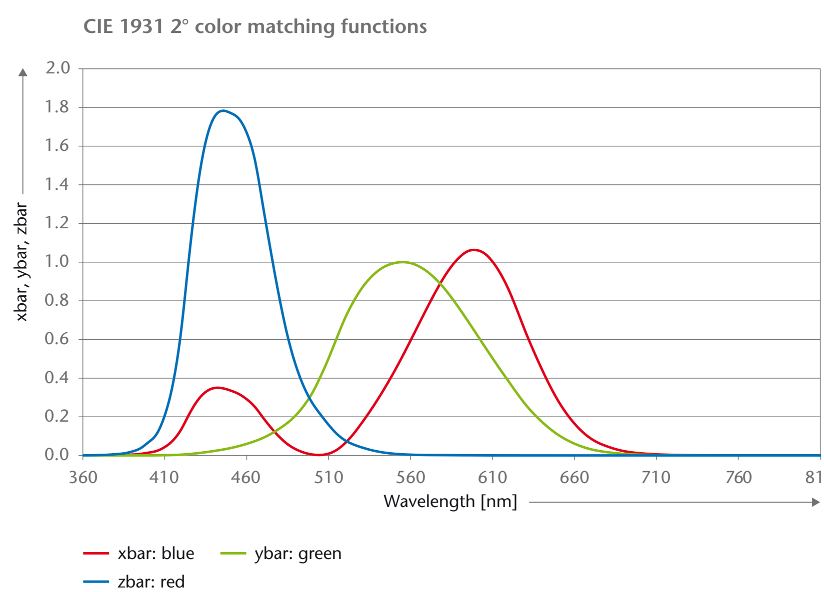


Fig. 1
Color matching functions $\bar{x}(\lambda)$, $\bar{y}(\lambda)$, and $\bar{z}(\lambda)$ for the CIE 2° standard colorimetric observer. The curve $\bar{y}(\lambda)$ is identical to the spectral luminous efficiency function $V(\lambda)$ for photopic vision.

Measurement of brightness

Within the CIE 1931 standard colorimetric system, the color-matching function $\bar{y}(\lambda)$ is identical to the spectral luminous efficiency function $V(\lambda)$. Thus, if a precision filter with a spectral transmission factor $\tau_y(\lambda)$ is used, brightness measurements may also be carried out alone (determination of the tri stimulus value Y).

Filter design

SCHOTT's range of products includes optical filter glass combinations which, given the below simplifications, allow an approximate determination of the tristimulus values and brightness, respectively, to be performed:

1. The sensitivity curve a typical silicon detector $S(\lambda)$ has been taken as a basis.
2. Since the curve of the color-matching function $\bar{x}(\lambda)$ consists of two adjacent, bell-shaped curves, it can be represented by two selective precision filters, with the following approximation:

$$a_1 \cdot \tau_{x1}(\lambda) + a_2 \cdot \tau_{x2}(\lambda) \approx \frac{\bar{x}(\lambda)}{S(\lambda)},$$

   where $\tau_{x1}(\lambda)$ describes the curve of transmission of the short-wave band, while $\tau_{x2}(\lambda)$ describes that of the long-wave band. Appropriately, the wavelength-independent constants a_1 and a_2 are determined empirically.
3. The $\bar{y}(\lambda)$, and $\bar{z}(\lambda)$ curves are similar so that but only one filter has been computed for each of both curves.

The conditions set forth below apply to optical filter glass combinations SFK 100A, SFK 101B and SFK 102A exhibiting the spectral transmission factors of $\tau_{SFK100A}(\lambda)$, $\tau_{SFK101B}(\lambda)$, and $\tau_{SFK102A}(\lambda)$:

$$a_1 \cdot \tau_{SFK100A}(\lambda) + a_2 \cdot \tau_{SFK100A}(\lambda) \approx \frac{\bar{x}(\lambda)}{S(\lambda)}$$

$$b \cdot \tau_{SFK101B}(\lambda) \approx \frac{\bar{y}(\lambda)}{S(\lambda)} = \frac{V(\lambda)}{S(\lambda)}$$

$$c \cdot \tau_{SFK102A}(\lambda) \approx \frac{\bar{z}(\lambda)}{S(\lambda)}$$

with the wavelength-independent constants a_1, a_2, b, and c to be determined.

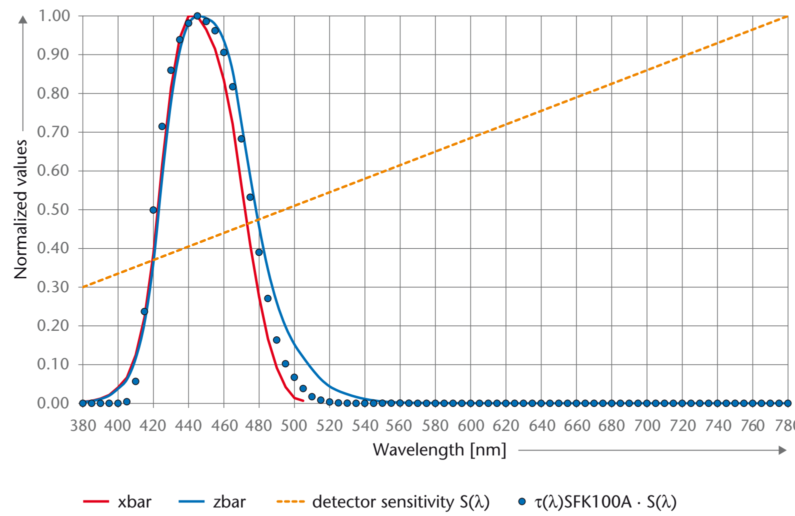


Fig. 2
Optical filter glass combination SFK 100A with $\tau_{max} \approx 0.43$ (all curves are normalized to 1).

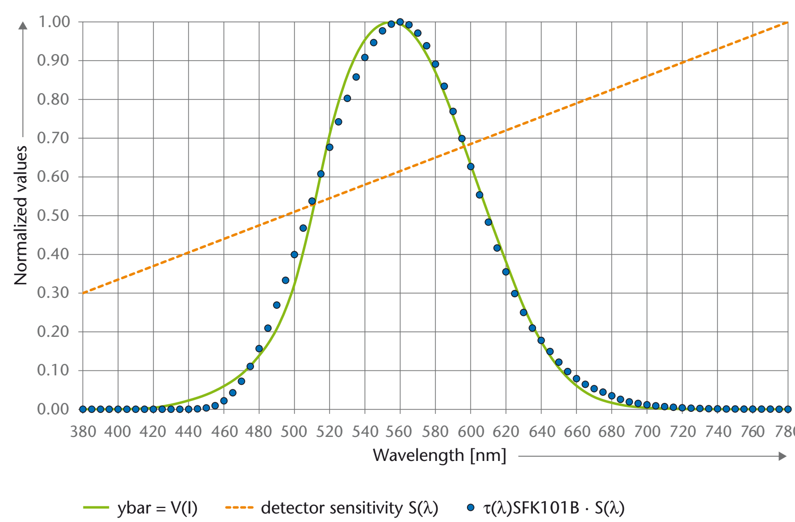


Fig. 3
Optical filter glass combination SFK 101B with $\tau_{max} \approx 0.39$ (all curves are normalized to 1).

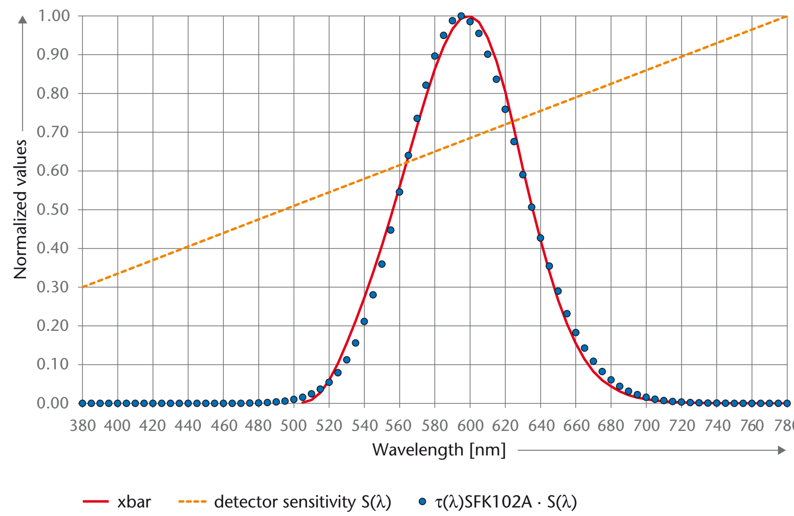


Fig. 4
Optical filter glass combination SFK 102A with $\tau_{max} \approx 0.08$ (all curves are normalized to 1).

Filter properties

The optical filter glass combinations' typical degree of adjustment is evident from Figs. 2–4, that also show the curve of spectral sensitivity of the silicon detector. The transmission curves apply to 20 °C temperature, and there is a relatively low and mostly negligible temperature dependence. First-rate glass melts are chosen for manufacturing of the filters, and great attention is paid to the blocking of sensitivity ranges not desirable outside the spectral regions marked. Each of the glass filter combinations is cemented with the aid of epoxy resin. The liners withstand temperatures up 70 °C, and can be exposed to up to 100 °C for a short time.

In cases of high levels of atmospheric humidity, the use of protective glasses and the embedding in mountings are recommended.

Delivery and dimensions

Glass filter combinations for colorimetry: SFK 100A, SFK 101B, SFK 102A (these three filters make up one set).

Glass filter combination for brightness measurements: SFK 101B.

Standard dimensions: 50 x 50 mm and 50 mm in diameter.
Dimensional tolerances: + 01 – 0.3 mm
Max. dimension: 100 x 100 mm
Min. dimension: 10 mm in diameter
Max. thickness: 11 mm

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