SCHOTT
glass made of ideas

Optical Filter Glass 2024

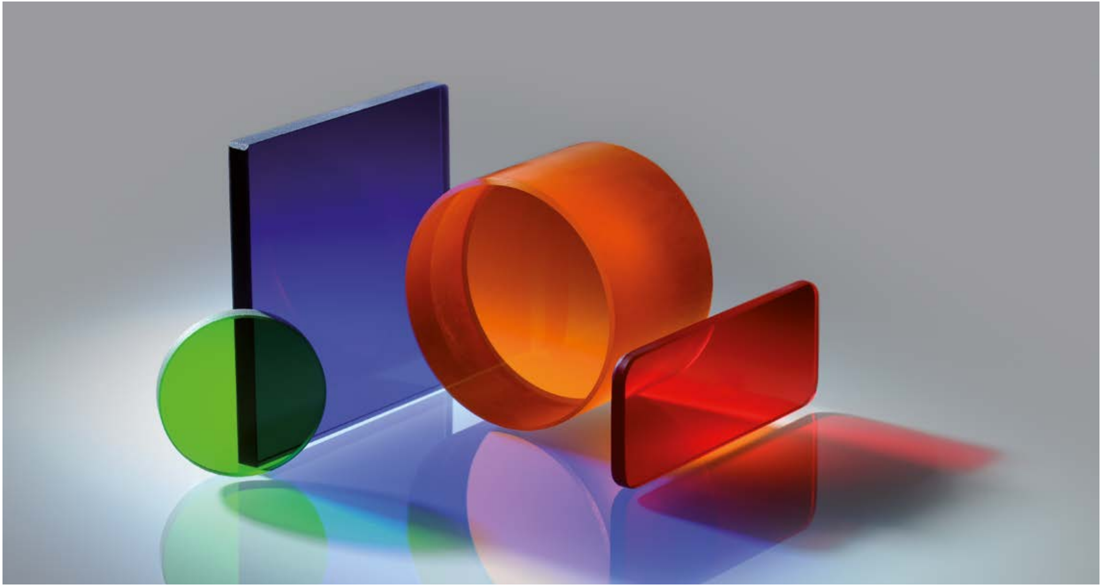
Optical Filter Glass

SCHOTT is a leading international technology group in the areas of specialty glass and glass ceramics. With more than 130 years of outstanding development, materials, and technological expertise we offer a broad portfolio of high-quality products and intelligent solutions that contribute to our customers' success.

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 70 filter glasses, 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

The cover image shows a prototype for laser safety goggles.
Curved, high absorption filter glass protects against UV, blue and green laser light and is particularly transmittant in long-wavelength ranges.



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Optical Filter Glass

Part I – Description

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 colored if their filter effect lies within the visible light spectrum. For more than 135 years, filters from SCHOTT have been known for their particularly high quality, purity, and outstanding properties.

Currently, the SCHOTT Advanced Optics portfolio comprises more than 70 different optical filter glass types, all produced with great care using sophisticated industrial processes. The glasses have the following advantages:

- High transmittance
- High blocking
- Filter spectra with virtually no dependency on angle of incidence.
- Superior quality, reliability, and durability
- No polarization effects
- Experience in meeting high-quality surface needs, extremely thin products and small tolerances in processing/manufacturing complex glass types
- Excellent adhesion properties for optical coatings
- All color filter glass types can be used as substrates for thin film coating with interference filters. This has specific benefits (absorption properties of a colored filter glass and the reflection properties of the interference filters) that can be combined into one optical filter.
- In special melts, glass properties can be tailored to provide optimal technical solutions.

SCHOTT's optical filter glass portfolio is the product line of choice for system designers and optical engineers and is being constantly updated according to market needs. While building on its capabilities, SCHOTT has also continuously expanded its optical filter glass portfolio.

The following filter glasses have been added in this edition:

- N-WG205, RG905, BG59 and S8851
- S7000, S7005, S7010N

SCHOTT's optical filters are described in two parts: Part I entitled "Description" provides information about the most important criteria on the materials and characteristics of optical filters. Part II entitled "Properties" contains additional detailed material data and specifications.

If any information not covered in this catalog is needed, please contact a representative of our world wide sales team. Our global team of experts is available to advise and help find the best solution for your specific needs.

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 catalog** without prior notice.

This catalog has been compiled with the utmost care. However, we assume no liability in the unlikely event that there are content or printing errors.

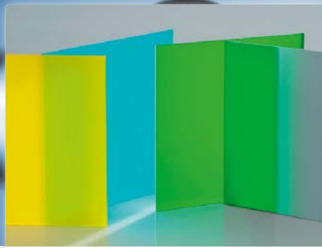
The release of this catalog replaces all previous publications.

January 2024

Welcome to our shop for optical materials

schott.com/shop/advanced-optics

Optical Glass



Optical Filter Glass

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1 Introduction

1.1 General information on listed data

Any data listed in this catalog without tolerance is to be understood as a reference value. Only those values listed in Chapter 2 in "Properties" under "Guaranteed spectral values for short-pass and bandpass filters", "Guaranteed values for NVIS filters", "Guaranteed spectral values for neutral density filters", "Guaranteed spectral values for long-pass filters" and "Guaranteed spectral values for multi-band-pass filters" are guaranteed values. The graphically depicted internal transmittance curves are reference curves and serve as an initial overview to assist you in finding the most suitable filter type for your application.

Chapter 1 of the "Description" part 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 the 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 cover topics such as further processing of optical filter glass and applications.

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

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

On request, more accurate reference values can be given, and guaranteed values can be adapted, when possible, to meet your requirements. We can of course also provide you with additional properties, measured or guaranteed, on request.

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

SCHOTT Advanced Optics produces and distributes special materials and components in accordance with the professional standards of our global Environmental, Health and Safety Management to prevent environmental pollution and to conserve natural resources. SCHOTT Advanced Optics also follows the procedures and philosophy of our global Quality Management System. The purchasing and handling of raw materials, the melting of batches, hot forming, and coating are strictly carried out according to established safety procedures and fulfill material compliance requirements.

All optical materials in this catalog comply with the requirements of the European Directive 2011/65/EU (RoHS). The optical materials featured in this catalog contain neither mercury (Hg) nor chromium VI (CrVI), nor PBB and PBDE flame retardants. 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 Directive 2011/65/EU.

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

1.3 SCHOTT optical filter glass: Product portfolio

The optical filter glass portfolio of SCHOTT consists of the following filter types in the UV to NIR range:

- **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
- **Neutral density filters** that exhibit nearly constant transmission, especially in the visible range

Filter glass can be used in different thicknesses to achieve the right effect. SCHOTT also has 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. These include chemical resistance, bubble quality, and tolerances of transmission properties.

The graphs in the "Properties" part 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.

1.4 Positive list

SCHOTT Advanced Optics offers one of the world's broadest portfolios of optical filter glasses. Our portfolio glasses are melted regularly and have long-term availability. These glasses will remain in our portfolio for at least the next 5 years. For details on this self-commitment and our life cycle management, please see the Positive list, which is updated every year, on our website.

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 color appearance of the filter glasses and their optical functions.

Many other properties are also related to the chemical composition of these glasses and the ‘Classification by material’ section 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 when 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 UV cutoffs, 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*

Special filter

S Filters with special properties or for special applications

2.2 Classification by material

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

* NIR as defined in ISO 4007 is the wavelength range IR-A from 780 nm to 1,400 nm

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 spectral properties and coloration of glasses. This effect depends on the nature and quantity of the coloring substances, the oxidation state of the coloring ions, 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 longpass filters 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 RG905 and 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 transmittance is only controlled for the wavelengths, which are mentioned in the "Guaranteed spectral values" of each data sheet (see also Part 2, Chapter 2 of this booklet). The variations are usually low between the minimum and maximum wavelength listed in the guaranteed spectral values. However, variations might be much larger outside this region. The colloidally colored glasses also exhibit deviations within a melt due to technically unavoidable temperature gradients during the striking process.

The "Properties" chapter lists the permissible transmission deviations for specific wavelengths of each glass type (see "Guaranteed spectral values for shortpass and bandpass filters", "Guaranteed values for NVIS filters", "Guaranteed spectral values for neutral density filters", "Guaranteed spectral values for long-pass filters" and "Guaranteed spectral values for multi-band-pass filters"). These spectral properties are measured and documented for each production batch. Through selection and reservation of suitable melts and through variations in the optical filter glass thickness, tighter tolerances can be achieved.

3 Optical properties

The following chapter covers the important definitions and formulas that are used to describe the optical properties of filter glasses. The terms and definitions are in accordance with ISO 23364.

In addition, the relevant optical features of 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. Variations in refractive index of the order of ± 0.01 are possible from batch to batch, but homogeneity within a batch is far better.

3.2 Reflection loss at the 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 $P(\lambda)$. P is the Greek letter "Rho". Under the constraints of incoherent radiation and perpendicular incidence, and considering multiple reflections, equation 1 applies.

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

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 spectral transmittance $\tau(\lambda)$ or internal spectral transmittance $\tau_i(\lambda)$. The difference between the two is described below:

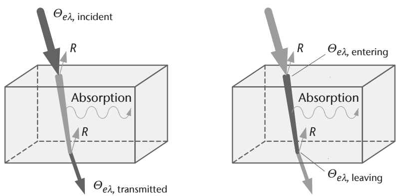


Figure 3.1
Definition of spectral transmittance (left) and internal spectral transmittance (right)

Definition of **spectral transmittance**:

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

Spectral transmittance $\tau(\lambda)$ in equation 2 is the ratio of the transmitted (energetic) spectral flux $\Phi_{e\lambda,\ \text{transmitted}}$ to the incident (energetic) spectral flux $\Phi_{e\lambda,\ \text{incident}}$. Hence $\tau(\lambda)$ describes the transmittance of the absorbing glass filter considering the reflection losses at the front and rear sides of the filter. Spectral transmittance can be easily measured. It is important to note that, in the 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 transmittance $\tau(\lambda)$.

Definition of internal spectral transmittance:

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

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

Using *R*:

$$\tau = \frac{(1-R)^2\,\tau_i}{1-\tau_i^2R^2} \quad \text{and} \quad \tau_i = -\frac{(1-R)^2}{2R^2\tau} + \sqrt{\frac{(1-R)^2}{2R^2\tau} + \frac{1}{R^2}}$$

Or using the approximation with the reflection factor P(λ):

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

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

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

$$\tau_{i,\,d_1}(\lambda) = \left(\tau_{i,\,d_2}(\lambda)\right)^{\frac{d_1}{d_2}} \quad (5)$$

$\tau_{i,d_1}(\lambda)$: 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:

$$\tau_{d_1}(\lambda) = P(\lambda) \cdot \left(\tau_{i,d_2}(\lambda)\right)^{\frac{d_1}{d_2}} \quad (6)$$

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

$$d_1 = d_2 \frac{\log\left(\tau_{d_1}(\lambda)\right) - \log\left(P(\lambda)\right)}{\log\left(\tau_{i,d_2}(\lambda)\right)} \quad (7)$$

3.4 Derived optical parameters

The following parameters can be calculated from transmittance $\tau(\lambda)$ and internal transmittance $\tau_i(\lambda)$.

3.4.1 Spectral optical density

$$D(\lambda) = \log_{10} \frac{1}{\tau(\lambda)} \quad (8)$$

3.4.2 Spectral extinction (absorbance)

$$E(\lambda) = \log_{10} \frac{1}{\tau_i(\lambda)} \quad (9)$$

3.4.3 Spectral diabatie

10 $$\Theta(\lambda) = 1 - \log_{10}\left(\log_{10}\frac{1}{\tau_i(\lambda)}\right) = \log_{10}\frac{10}{E(\lambda)}$$

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 spectral transmittance τ.

3.4.4 Luminous transmittance

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

Luminous transmittance (according to ISO 23364:2022) is the ratio of luminous flux transmitted by a filter with the 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 graphs

Internal transmittance for the appropriate reference thicknesses are presented graphically in the "Properties" part. The wavelength from 200 nm to 1200 nm is shown as the abscissa. 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 orientation purposes.

3.6 Spectral characterization of optical filters

Optical filters are described by their spectral characteristics and can be divided into several groups be categorized according to their function. The typical functions of filter glass are defined and explained below.

Limit values and tolerances in the specifications in our catalog always refer to a reference thickness.

3.6.1 Longpass filters

A longpass filter allows long wavelengths to pass through and blocks short wavelengths (see Fig. 3.2). Our longpass filters are steep-edge filters characterized by excellent absorption in the blocking range and a short transition into the transmittance range. They provide almost perfect transmittance in long wavelength ranges.

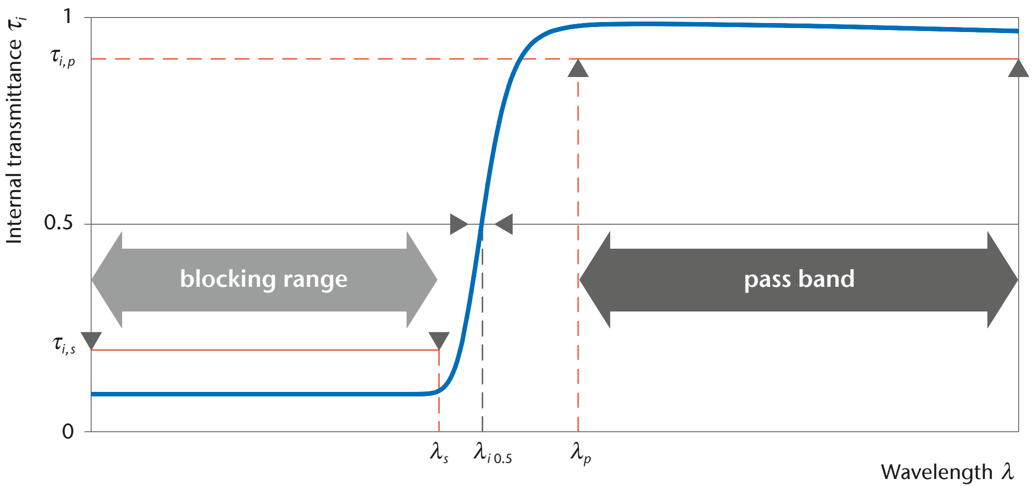


Figure 3.2
Longpass filter

Longpass filters are specified by the following values:

$\lambda_{i\,0.5}$: 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
Thus: $\tau_i(200\text{ nm to }\lambda_s) < \tau_{i,\,s}$

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 $\tau_{i,\,p2} = 0.97$.
Thus: $\tau_i(\lambda_p\text{ to }2000\text{ nm}) < \tau_{i,\,p}$ or
$\tau_i(\lambda_{p1}\text{ to }\lambda_{p2}) < \tau_{i,\,p1}$ and $\tau_i(\lambda_{p2}\text{ to }2000\text{ nm}) < \tau_{i,\,p2}$

3.6.2 Shortpass filters

A shortpass filter allows short wavelengths to pass while long wavelengths are blocked (see Figure 3.3). Typically, the slope at the transition between the pass band and blocking range of a longpass filter is much steeper than the slope of a shortpass filter.

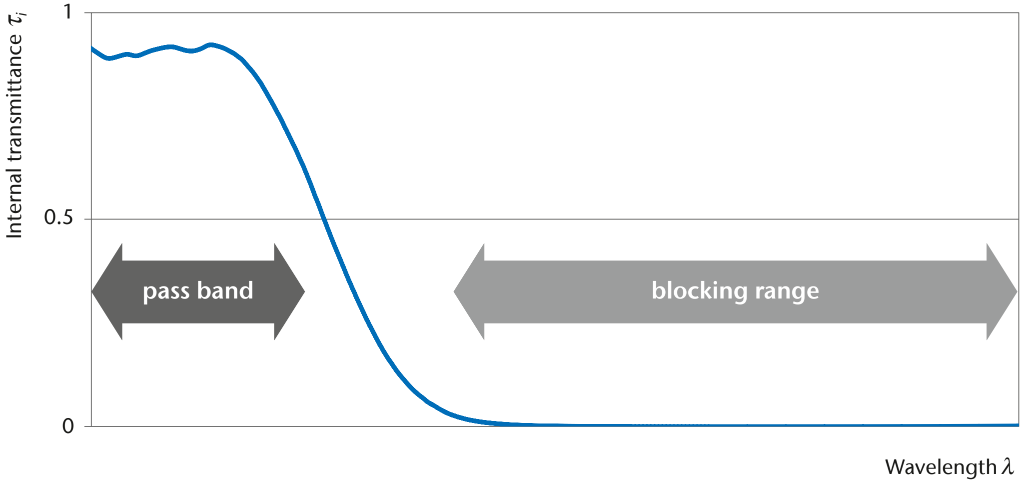


Figure 3.3
Shortpass filter

3.6.3 Bandpass filters

Bandpass filters selectively transmit a desired wavelength range. They are characterized by a section of high transmittance (pass band) being enclosed by sections of low transmittance (blocking ranges) (see Figure 3.4).

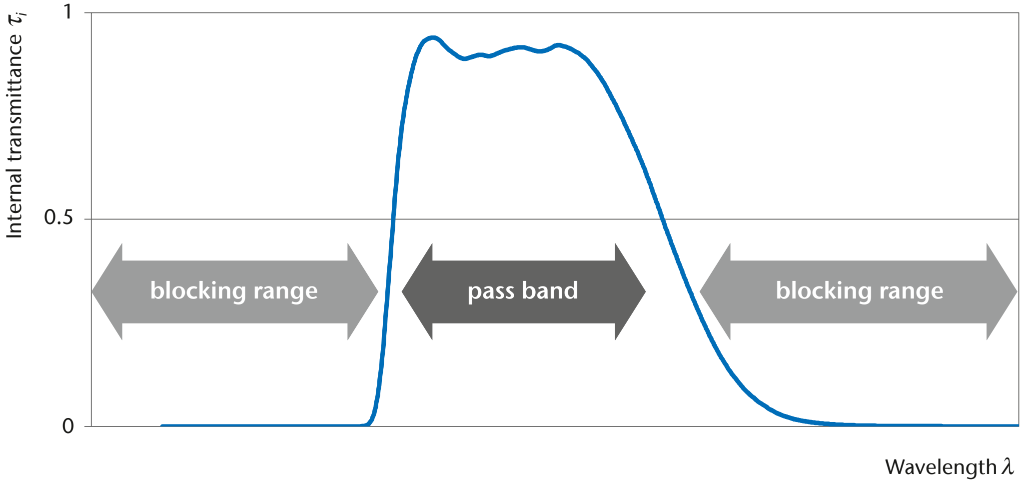


Figure 3.4
Bandpass filter

3.6.4 Neutral density filters

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

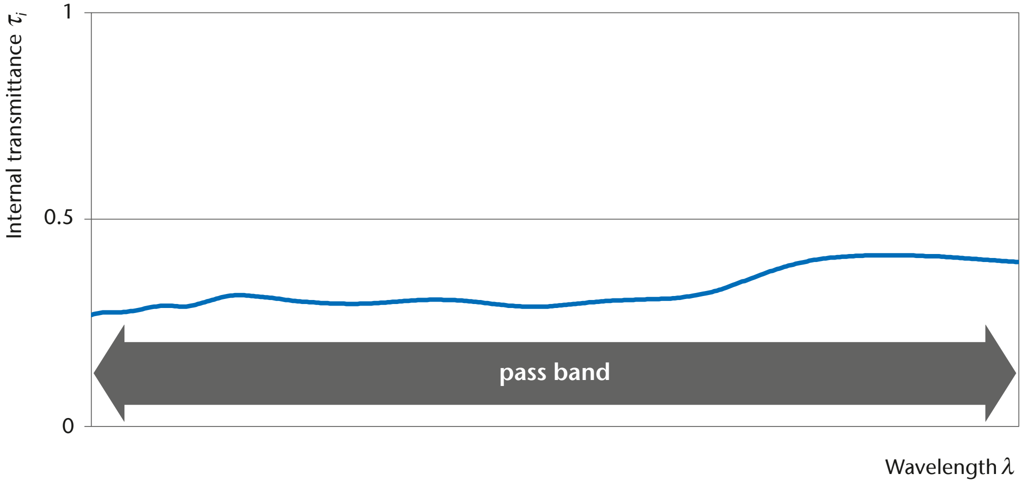


Figure 3.5
Neutral density filter

3.6.5 Overview of transmittance properties

The figure in the back pocket of this booklet depicts the transmittance properties of all our optical glass filters. To give a clear overview, the graphs are sorted into eleven groups. The scale of transmittance is linear, and the graphs always refer to the reference thickness specified in the data sheet.

3.7 Dependence of spectral transmission on temperature

The cutoff wavelength $\lambda_{i\,0.5}$ of longpass filters shifts to higher wavelengths with increasing temperature. In the "Properties" part, the temperature coefficient of the edge wavelength $\Delta\lambda_{i\,0.5}/\Delta T$ [nm/K] is listed for all longpass filters. These are average values.

For bandpass filters and filters with shallow slopes, 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 relatively pronounced luminescence of optical filter glasses is only of practical interest when these filters are to be used to measure the luminescence of materials. Before using optical filter glasses as excitation filters, i.e. for spectral isolation of the exciting radiation, the suitability of the glass should be checked on a case-by-case basis, as the fluorescence properties of some glass types may vary from batch to batch.

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 the color metric conventions set down by the CIE (see EN ISO/CIE 11664). In the color space for the 1931 CIE 2° colorimetric standard observer, the brightness reference value is identical to the standard color value Y. To enable a 3D description of the color stimulus in a diagram, a transformation is used to obtain a color locus in a plane diagram. For optical applications, the 1931 and 1976 CIE transformations have proven favorable. There are two ways to describe chromaticity coordinate F in the 1931 CIE color diagram (see Figure 3.6): Either the chromaticity coordinates x and y, or the dominant wavelength λ_d and the excitation purity $P_e = DF : DS$.

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

These apply to:

- Filter glass thicknesses of 1, 2, and 3 mm
- The following standardized illuminations:
  - Standard illuminant A (Planckian radiator at 2856 K)
  - Planckian radiator at 3200 K
  - Standard illuminant D65, standard daylight
- CIE 2° colorimetric standard observer
- 20 °C temperature

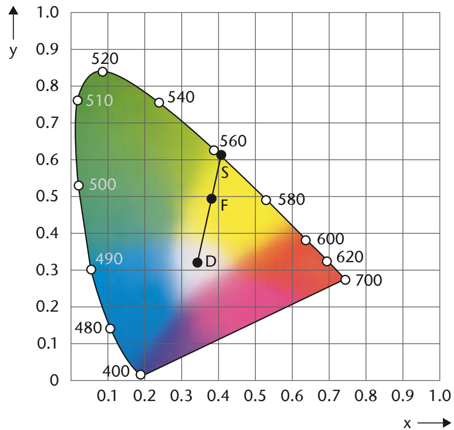


Figure 3.6
Optical filter glass color according to the CIE 1931 definition
D: Chromaticity of the radiation source, for example D65
S: Point where expansion $\overline{DF}$ intersects the spectral locus at λ_d

The tristimulus values listed in the data sheets are only reference values.

Chromaticity coordinates that are 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 x and y coordinates by way of the following formula:

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

with:

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:

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

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:

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

with:

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 (combination of filter and light source)
r = radius tolerance in the 1976 UCS chromaticity coordinate system for the specified color

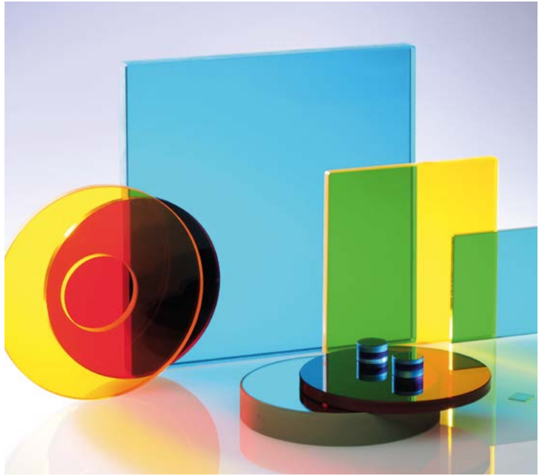
3.9.1 Brightness/photopic transmittance

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 1 %.

Example: Brightness $Y = 57$ corresponds to photopic transmittance = 57 %

3.9.2 Measuring chromaticity coordinates

SCHOTT provides special filter glass combinations (SFK types) that can be used to emulate the spectral value functions $\bar{x}(\lambda)$, $\bar{y}(\lambda)$, $\bar{z}(\lambda)$ of the CIE 2° colorimetric standard observer. These SFK filters are customized to the sensor characteristic used, and can be used to measure the chromaticity coordinates. Figures 11.12 to 11.14 show examples of normalized internal transmittance graphs (see Chapter 11).



Optical filter glasses in different geometries and delivery formats (coated, bonded, etc.).

4 Thermal and mechanical properties

To develop an assortment of optical filter glasses covering the largest possible spectral area, it was necessary to develop glasses with extreme filtering properties, numerous colorants with different concentrations and many different base glasses. The "Properties" part lists the following important properties for each optical filter glass type. These are typical values that are to be used as reference values. The range of variation of the specified values from batch to batch is not known. Exact measurements can be made on request for a batch.

4.1 Mechanical density ρ in g/cm³

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/cm³.

4.2 Knoop hardness $HK_{[0.1/20]}$

The Knoop hardness expresses the amount of surface changes in a brittle material after the indentation of a test diamond at a given force and time. The listed values are measured in accordance with ISO 9385 at a test force of 0.9807 N and an effective test period of 20 s. The test is performed at room temperature and the measurement uncertainty is ± 35 $HK_{[0.1/20]}$.

4.3 Strength

The strength of glass is not only a material property, but also a function of surface quality. This means that the strength is highly dependent on the surface finish and edge quality of a component. Thus, small scratches can significantly lower the strength. Our technical information "TIE 33: Design strength of optical glass and ZERODUR®"[1] provides additional information on the strength of glass and relevant design issues.

[1] Technical Information (TIE's) can be downloaded from the "Download section" of the product page.

Mechanical strength and thermal shock resistance can be increased by thermal or chemical toughening. See Chapter 7.2.

4.4 Transformation temperature *Tg* in °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 in 10^{-6}/K

The coefficient of thermal expansion (CTE or α) gives the relative change in the length of a glass $\Delta l/l$ 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:

$$\frac{\Delta l}{l} = \alpha\,\Delta T$$

In the catalog, the linear coefficients of thermal expansion are given for two temperature ranges:

$\alpha_{-30/+70\,°C}$ denotes the linear coefficient of thermal expansion in the range of −30 °C to 70 °C.
$\alpha_{20/300\,°C}$ denotes the linear coefficient of thermal expansion in the range of 20 °C to 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 range of 20 °C to 200 °C due to their low transformation temperature.

Values for other temperature ranges can also be measured on request.

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".

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.

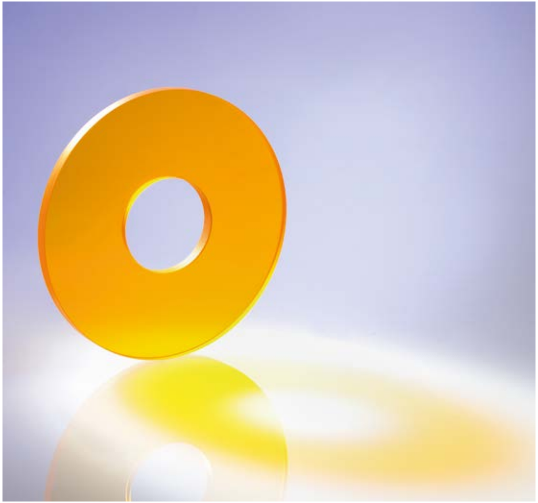
The stain resistance class is determined according to the following procedure: The plane-polished glass sample to be tested is pressed onto a test cuvette, which has a spherical depression of max. 0.25 mm depth containing a few drops of test solution I or II.

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 glass surface 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.

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

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



CNC machined filter glass

5.2 Acid resistance

Acid resistance according to ISO 8424:2023 classifies the behavior of glass surfaces that come into contact with large quantities of acidic solutions (practical examples: perspiration, laminating substances, carbonated water, etc.). Acid resistance is denoted by a two or 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.

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

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

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.

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

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

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 may exhibit a slightly cloudy residue. Initially, this residue can be removed using glass polishing compounds. More severe attacks ruin the surface polish quality. This effect of corrosion is caused by warm humidity. Several factors influence the corrosion of filter glasses: Temperature has the biggest impact here. Other factors include relative humidity, surface quality and surface contamination. Therefore, it is difficult to give an exact rating of sensitivity to warm humidity. With respect to this behavior, our filter glasses are classified into four groups:

“Resistant glasses” group No symbol

No substantial surface change occurs in these filter glass types. A change in the surface is only possible under extreme conditions such as 85 °C and 85 % relative humidity for hundreds of hours.

“Robust glasses” group Symbol:

Glass types marked with **a closed umbrella** withstand warm humidity testing at 60 °C and 90 % relative humidity for more than 48 hours.

“Sensitive glasses” group Symbol:

Glass types marked with **an opened umbrella** should be used and stored in a moderate climate or in closed work and store rooms (constant temperature below 35 °C, relative humidity less than 60 %). A desiccant is to be used when wetness is a possibility. For use and storage in open air and tropical climates, it is advisable to apply protective coatings which SCHOTT can provide upon request.

“Delicate glasses” group Symbol:

For optical filter glass types marked with **two opened umbrellas**, changes in the glass surface are possible after several months of normal storage. These glasses are to be handled with care. Any contact with water or warm humidity should be avoided. A desiccant is to be used for long-term storage of unprotected glass. For this reason, protective coatings are recommended which SCHOTT can provide upon request.

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 radiation wavelength, the higher the solarization effect.

Toughened filter glass with scratch-resistant coating.

The solarization effect primarily manifests itself by a shift of the shortwave-located edge to longer wavelengths and a reduction of the transmission in the pass range. The effect does not affect the structure and stability of the glass, so there is no tendency to brittleness and weakening of mechanical stability as in the case of plastic. 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 optical filter glass solarization is heavily dependent on the spectral distribution and intensity of the light source and the duration and 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" part.

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 a particularly small number of bubbles. However, it is not always possible to avoid bubbles in the glass. The description of bubble and inclusion content varies between unpolished glass and polished optical filter components. The reason is that bubble classes for matte plates and raw glass are defined for a fairly large volume of 100 cm^3, whereas polished optical filter components are often much smaller. It is therefore not unusual for bubble-free components to be manufactured even from bubble class 3 filter glass.

6.1.1 Bubbles and inclusions in matte optical filter glass plates

The bubble content of an optical filter glass is characterized by the overall 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 detected individual bubbles that are larger than 30 µm.

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

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

Table 6.1
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 be easily inspected. Therefore, any desired internal quality can be produced by selecting the appropriate raw material.

The internal quality of polished filter glass components is specified in accordance with the ISO 10110-18:2018 standard. If no specifications are made by the customer on ordering, the permissible amount of bubbles and inclusions is 1/5 x 0.4 for all polished filter sizes. (This complies with the recommendation from ISO 10110-11:2016 at a standard filter size of over 30 mm and up to 100 mm.) This specification is only valid 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 10110-11:2016 apply for 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 differing from the base glass. Classes of striae are defined in ISO 10110-18:2018. We use the shadowgraph method to determine the striae quality grade. Striae evaluation is dependent on the transparency of the optical filter glass. Thus, a specification for striae is only applicable for polished optical filter components.

Individual fine striae may be present in our standard quality glass.

6.3 Homogeneity of refractive index and wavefront

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.

For polished plano-parallel filters, we recommend customers to specify the deformation of the transmitted wavefront instead of flatness to avoid an over-specification of the surfaces. This also reduces uncertainty of the imaging properties of the polished component.

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 the special quality of the material, the accuracy of shape, excellent surface quality, and outstanding optical performance. The international standard ISO 10110 defines the quality aspects for 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 must 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.

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 Thermal toughening

Absorbing optical filter glass in most cases undergoes uneven heating due to light irradiation. The low thermal conductivity of optical filter glass prevents rapid thermal equilibrium.

Temperature gradients are therefore created between both the front and back surfaces and, in particular, between the center and the edges of the optical filter glass. This causes bending stresses within the optical filter glass due to thermal expansion.

Thermal toughening of the optical filter glass enables improved resistance to larger temperature gradients or rapid temperature changes while also increasing flexural strength. The improved heat resistance of tempered optical filter glass causes minor deformation and possibly minor spectral value changes.

This means that the **limits defined for the guaranteed spectral values of a glass type can then not be adhered to**: Minor deviations need to be accepted by the customer or discussed with us at the time of ordering. !

For optical filter glasses which are placed in front of intense light sources, thermal toughening is required to increase their breaking strength. It must be ensured that glass temperatures do not exceed (*Tg* – 300 °C), or for a short time (*Tg* – 250 °C). If not, thermal toughening will weaken depending on temperature and time. Transformation temperature Tg is given for each type of colored glass in the table in the "Properties" part.

Appropriate action needs to already be taken during the design of equipment subject to thermal loads so as to minimize spatial or temporal temperature gradients – especially between the center and the edges of the glass plate (e.g. uniform illumination or slow change of temperatures). When installing filters in holders and housings, care must be taken to ensure that no additional mechanical forces act on the glass. Direct contact between metal and glass should be avoided. It is recommended to use insulating intermediate layers made of appropriate materials.

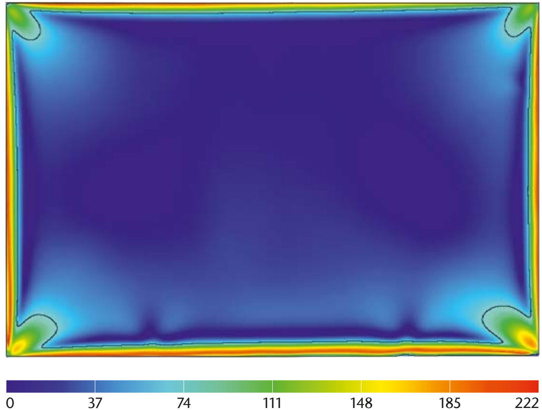


Figure 7.1
Visualization of stress birefringence in a thermally toughened filter. The image shows the measured stress-optic path difference in nm at a sample thickness of 3 mm.

7.3 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
- Scratch-resistant coatings
- Mirror coatings
- All types of interference filters
- Electrically conductive coatings
- Moisture-proof coatings

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

BG filters are ideal as NIR cut filters.

IR-transmittant longpass filters

Optical Filter Glass

Part II – Properties

8 Optical Filter Glass: product line

8.1 Portfolio glasses

The color filter glass product line comprises more than 70 optical filter glass types.

The glasses BG59, N-WG205, RG905, S8851, S7000, S7005 and S7010N are new additions to the portfolio.

Our portfolio glasses are melted regularly and have long-term availability. These glasses will remain in our portfolio for at least the next 5 years. For details on this self-commitment and our life cycle management, please see the Positive list, which is updated every year, on our website.

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

UV Bandpass	Bandpass		Multi-bandpass	Longpass		Shortpass	Neutral density
UG1	BG3	BG60	BG36	N-WG205	OG515	KG1	NG1
UG2A	BG7	BG61	S7005	N-WG280	OG530	KG2	NG3
UG5	BG18	BG62	S7010N	N-WG295	OG550	KG3	NG4
UG11	BG25	BG66	S8008G	N-WG305	OG570	KG5	NG5
			S8802	N-WG320	OG590		NG9
	BG38	S8612	S8806A	S7000			NG1
	BG39	S8022	S8808	N-WG360*	RG610		
	BG40	S8023	S8851	S8003N*	RG630		
	BG42			GG395	RG645		
	BG55	VG9		GG400	RG665		
	BG59			GG420	RG695		
				GG435	RG715		
				GG455	RG780		
				GG475	RG830		
				GG495	RG850		
					RG9		
					RG905		
					RG1000		

Table 8.1: SCHOTT portfolio glasses: long-term availability

* N-WG360 and S8003N are identical

8.2 Inquiry glasses

The following glass types are only melted on request:

Bandpass	Multi-bandpass	Longpass	Shortpass	Color conversion	Neutral density
BG4	BG20	WG225	KG4	FG13A	NG10
BG12	S8003G	GG385			NG12
BG23	S8807				
BG24A	S8809				
BG26	S8817				
BG28					
BG34A					
BG50					
VG6					
VG14					

Table 8.2: Inquiry glasses that are only made on request

8.3 Data and tolerances

Any data listed in this catalog without tolerance is to be understood as a reference value. Only those values listed in Chapter 9 in the "Properties" part under "Guaranteed spectral values for shortpass and bandpass filters", "Guaranteed values for NVIS filters", "Guaranteed spectral values for neutral density filters", "Guaranteed spectral values for long-pass filters" and "Guaranteed spectral values for multi-band-pass 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.

9 Optical Filter Glass: guaranteed values

Our optical filter glasses are widely used in numerous applications because of their unique spectral properties. Although we are able to offer our glasses with high repeatability of certain spectral properties, it is not possible to control the whole range of wavelengths from UV to NIR. Instead, each glass has its own set of wavelengths that are characteristic to that glass type. During production, those wavelengths are constantly monitored and the melting process is adjusted to keep variations low.

Limit values of τ_i for shortpass and bandpass filters

Glass type	Thick-ness	$\tau_i(\lambda)$	$\tau_i(\lambda)$	$\tau_i(\lambda)$	$\tau_i(\lambda)$	$\tau_i(\lambda)$	$\tau_i(\lambda)$	$\tau_i(\lambda)$	$\tau_i(\lambda)$
UG1	1 mm	≥ 0.80 (365)	≤ 0.10 (405)	≤ 0.06 (694)	≤ 0.53 (750)				
UG2A	3 mm	≤ 0.07 (303)	≥ 0.81 (365)	≤ 0.10 (405)	≤ 0.04 (694)	≤ 0.52 (750)			
UG5	1 mm	≥ 0.80 (254)	≥ 0.94 (308)	≤ 0.5 (405)	≤ 0.05 (546)	≤ 0.05 (633)	≤ 0.85 (725)		
UG11	1 mm	≥ 0.06 (254)	≥ 0.90 (334)	≤ 0.001 (405)	≤ 0.26 (694)	≤ 0.32 (725)			
BG3	1 mm	≥ 0.94 (365)	≤ $5*10^{-5}$ (633)						
BG7	1 mm	≥ 0.25 (365)	≥ 0.78 (488)	≤ 0.08 (633)					
BG18	1 mm	≥ 0.30 (350)	≥ 0.65 (405)	≥ 0.88 (514)	≤ 0.25 (633)	≤ 0.03 (694)	≤ $5*10^{-4}$ (1060)		
BG25	1 mm	≤ 0.8 (334)	≥ 0.93 (405)	≤ 0.39 (488)	≤ 0.36 (725)				
BG38	1 mm	≥ 0.80 (350)	≥ 0.93 (405)	≥ 0.95 (514)	≤ 0.67 (633)	≤ 0.32 (694)	≤ 0.06 (1060)		
BG39	1 mm	≥ 0.60 (350)	≥ 0.85 (405)	≥ 0.93 (514)	≤ 0.30 (633)	≤ 0.03 (694)	≤ 0.001 (1060)		
S8612	1 mm	≥ 0.96 (500)	≥ 0.48 (600)	< 0.02 (700)					
BG40	1 mm	≥ 0.80 (350)	≥ 0.93 (405)	≥ 0.97 (514)	≤ 0.57 (633)	≤ 0.16 (694)	≤ 0.02 (1060)		
BG42	1 mm	≥ 0.40 (350)	≥ 0.65 (405)	≥ 0.88 (514)	≤ 0.27 (633)	≤ 0.03 (694)	≤ 0.002 (1060)		
BG55	1 mm	≥ 0.76 (405)	≥ 0.93 (514)	≥ 0.18 (633)	≤ 0.016 (694)	≤ $5*10^{-4}$ (1060)			
BG59	1 mm	≥ 0.37 (405)	≥ 0.42 (430)	≥ 0.72 (514)	≥ 0.42 (565)	≤ 0.02 (633)	≤ 0.02 (1500)		
BG60	1 mm	≥ 0.80 (405)	≥ 0.91 (514)	≥ 0.10 (633)	≤ 0.008 (694)	≤ 0.0015 (1060)			
BG60HT	1 mm	≥ 0.85 (405)	≥ 0.93 (514)	≥ 0.10 (633)	≤ 0.008 (694)	≤ 0.0015 (1060)			
BG61	1 mm	≥ 0.84 (405)	≥ 0.93 (514)	≥ 0.18 (633)	≤ 0.03 (694)	≤ 0.008 (1060)			

Glass type	Thick-ness	$\tau_i(\lambda)$	$\tau_i(\lambda)$	$\tau_i(\lambda)$	$\tau_i(\lambda)$	$\tau_i(\lambda)$	$\tau_i(\lambda)$	$\tau_i(\lambda)$	$\tau_i(\lambda)$
BG62	1 mm	≥ 0.73 (405)	≥ 0.89 (514)	≥ 0.08 (633)	≤ 0.005 (694)	≤ $5*10^{-4}$ (1060)			
BG62HT	1 mm	≥ 0.80 (405)	≥ 0.90 (514)	≥ 0.08 (633)	≤ 0.004 (694)	≤ $5*10^{-4}$ (1060)			
BG63	1 mm	≥ 0.95 (405)	≥ 0.96 (514)	≥ 0.50 (633)	≤ 0.25 (694)	≤ 0.16 (1060)			
BG64	1 mm	≥ 0.99 (405)	≥ 0.99 (514)	≥ 0.72 (633)	≤ 0.55 (694)	≤ 0.45 (1060)			
BG66	1 mm	≥ 0.815 (430)	≥ 0.89 (514)	≥ 0.615 (565)	≤ 0.0015 (694)	≤ $2*10^{-4}$ (1060)			
BG67	1 mm	≥ 0.70 (450)	≥ 0.80 (500)	≥ 0.65 (550)	≤ 0.19 (600)				
BG67HT	1 mm	≥ 0.75 (450)	≥ 0.83 (500)	≥ 0.65 (550)	≤ 0.19 (600)				
VG9	1 mm	≤ 0.21 (450)	≥ 0.67 (514)	≤ 0.15 (633)	≤ 0.07 (725)	≤ 0.18 (1060)			
VG20	1 mm	≥ 0.75 (450)	≥ 0.83 (500)	≥ 0.65 (550)	≤ 0.19 (600)				
RG9	3 mm	≤ 0.45 (720)	≥ 0.92 (800)	≤ 0.40 (1060)					
RG905	4 mm	≤ 0.002 (405)	≤ 0.08 (490)	≤ 0.002 (645)	≥ 0.96 (900)				
KG1	2 mm	≥ 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 mm	≥ 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 mm	≥ 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 mm	≥ 0.80 (365)	≥ 0.86 (500)	≥ 0.80 (600)	≤ 0.43 (700)	≤ 0.09 (800)	≤ 0.008 (900)	≤ $1*10^{-4}$ (1060)	≤ 0.001 (2200)

Table 9.1: Guaranteed spectral values for shortpass and bandpass filters: limit values of internal transmittance. The corresponding wavelength is indicated in the parenthesis in nm.

Tolerances for NVIS filters

Glass type	Thickness	Photopic transmittance		NVIS color according to MIL-STD-3009
		2100 K	1500 K	
S8022	2 mm	13.5 % ± 1.5 %	9.0 % ± 1.5 %	Green A
S8023	3 mm	15.0 % ± 1.5 %	10.5 % ± 1.5 %	Green A

Table 9.2: Guaranteed values for NVIS filters

Tolerance ranges of τ_i for neutral density filters

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

Table 9.3: Guaranteed spectral values for neutral density filters: tolerances for internal transmittance at different wavelengths

Tolerances and limit values for longpass filters

Glass type	Thickness	$\lambda_{i\,0,5}(\tau_i = 0.50)$	$\lambda_s(\tau_{i,\,s} \leq 1 \cdot 10^{-5})$	$\lambda_{p1}(\tau_{i,\,p1})$	$\lambda_{p2}(\tau_{i,\,p2})$
N-WG205	2 mm	205 nm ± 10 nm		270 nm (0.97)	
N-WG280	2 mm	280 nm ± 6 nm	230 nm	380 nm (0.99)	
N-WG295	2 mm	295 nm ± 6 nm	250 nm	400 nm (0.99)	
N-WG305	2 mm	305 nm ± 6 nm	260 nm	420 nm (0.99)	
N-WG320	2 mm	320 nm ± 6 nm	280 nm	470 nm (0.99)	
N-WG360*	2 mm	360 nm ± 6 nm	320 nm	500 nm (0.98)	
GG395	3 mm	395 nm ± 6 nm	340 nm	480 nm (0.92)	
GG400	3 mm	400 nm ± 6 nm	340 nm	480 nm (0.93)	
GG420	3 mm	420 nm ± 6 nm	360 nm	530 nm (0.93)	
GG435	3 mm	435 nm ± 6 nm	370 nm	520 nm (0.92)	
GG455	3 mm	455 nm ± 6 nm	390 nm	530 nm (0.92)	
GG475	3 mm	475 nm ± 6 nm	410 nm	550 nm (0.92)	
GG495	3 mm	495 nm ± 6 nm	430 nm	560 nm (0.92)	

Glass type	Thickness	$\lambda_{i\,0,5}(\tau_i = 0.50)$	$\lambda_s(\tau_{i,\,s} \leq 1 \cdot 10^{-5})$	$\lambda_{p1}(\tau_{i,\,p1})$	$\lambda_{p2}(\tau_{i,\,p2})$
OG515	3 mm	515 nm ± 6 nm	440 nm	580 nm (0.93)	
OG530	3 mm	530 nm ± 6 nm	460 nm	600 nm (0.93)	
OG550	3 mm	550 nm ± 6 nm	480 nm	620 nm (0.93)	
OG570	3 mm	570 nm ± 6 nm	500 nm	640 nm (0.93)	
OG590	3 mm	590 nm ± 6 nm	510 nm	660 nm (0.93)	
RG610	3 mm	610 nm ± 6 nm	530 nm	690 nm (0.94)	
RG630	3 mm	630 nm ± 6 nm	540 nm	710 nm (0.94)	
RG645	3 mm	645 nm ± 6 nm	560 nm	720 nm (0.94)	
RG665	3 mm	665 nm ± 6 nm	580 nm	750 nm (0.96)	
RG695	3 mm	695 nm ± 6 nm	610 nm	780 nm (0.96)	
RG715	3 mm	715 nm ± 9 nm	620 nm	810 nm (0.96)	
RG780	3 mm	780 nm ± 9 nm	610 nm	900 nm (0.97)	
RG830	3 mm	830 nm ± 9 nm	670 nm	950 nm (0.97)	
RG850	3 mm	850 nm ± 9 nm	700 nm	950 nm (0.90)	1200 nm (0.97)
RG1000	3 mm	1000 nm ± 6 nm	730 nm	1300 nm (0.90)	

Table 9.4: Guaranteed spectral values for longpass filters according to Chapter 3.6.1. For λ_p, the limit value of internal transmittance is given in the parenthesis.

* N-WG360 and S8003N are identical

Tolerance ranges of τ_i for multi-bandpass filters

Glass type	Thickness	$\tau_i(\lambda)$	$\tau_i(\lambda)$	$\tau_i(\lambda)$	$\tau_i(\lambda)$	$\tau_i(\lambda)$
BG36	1.0 mm	≥ 0.90 (405)	≤ 0.42 (450)	≥ 0.90 (650)	≤ 0.01 (800)	
S8802	3.5 mm	0.150 ± 0.025 (445)	0.305 ± 0.035 (555)	0.275 ± 0.035 (630)		
S8806A	2.5 mm	> 0.71 (455)	> 0.769 (550)	0.002 ± 0.002 (580)	0.900 ± 0.030 (618)	
S8808	3.5 mm	0.256 ± 0.030 (445)	0.320 ± 0.015 (555)	≤ 0.015 (580)	0.285 ± 0.030 (620)	
S8809	2.2 mm	0.196 ± 0.033 (440)	0.2346 ± 0.032 (550)	0.229 ± 0.027 (620)		
S8851	2.0 mm	≥ 0.966 (710)	0.414 ± 0.028 (805)	0.578 ± 0.034 (976)	0.320 ± 0.023 (1222)	0.290 ± 0.023 (1945)

Table 9.5: Guaranteed spectral values for multi-bandpass filters. The corresponding wavelength is indicated in the parenthesis in nm.

10 Optical Filter Glass: references values

The following data is only for reference. If exact values are needed, please contact us with your request for special measurements.

Glass type	Density ρ in g/cm³	P_d	n_d	Bubble class	Chemical resistance FR	Chemical resistance SR	Chemical resistance AR	T_g	$HK_{[0.1/20]}$	CTE in 10^{-6}/K −30 °C/+70 °C	CTE in 10^{-6}/K +20 °C/+300 °C	T_K in nm/K	Sensitivity*
UG1	2.77	0.913	1.54	1	0	1.0	1.0	603 °C	482	7.9	8.9		UV
UG2A	2.60	0.918	1.52	2	0	1.0	1.3	484 °C	–	8.7	9.9		UV
UG5	2.85	0.914	1.54	2	0	3.0	2.0	462 °C	407	8.1	9.4		UV
UG11	2.92	0.908	1.56	2	0	3.0	2.2	545 °C	440	7.8	9.0		UV
BG3	2.55	0.921	1.51	1	0	1.0	1.0	478 °C	438	8.8	10.1		UV
BG7	2.60	0.918	1.52	1	0	1.0	1.0	447 °C	441	8.7	10.0		
BG18	2.68	0.914	1.54	2	0	2.0	2.0	457 °C	462	7.4	8.9		
BG25	2.56	0.920	1.51	1	0	1.0	1.0	459 °C	434	8.9	10.2		UV
BG38	2.66	0.916	1.53	2	0	2.0	2.0	482 °C	472	7.5	8.9		
BG39	2.74	0.914	1.54	2	0	5.1	3.0	322 °C	386	11.6	13.1**		
S8612	2.66	0.913	1.54	1	0	3.0	3.0	391 °C	470	–	9.5		
BG40	2.74	0.916	1.53	1	0	5.1	3.0	313 °C	383	11.9	13.7**		
BG42	2.69	0.914	1.54	2	0	2.0	2.0	475 °C	467	7.3	8.7		
BG55	2.65	0.914	1.54	2	0	2.0	2.0	453 °C	504	7.2	9.1		
BG59	2.81	0.911	1.55	0	0	5.2	3.0	411 °C	431	9.7	11.5		
BG60	2.83	0.914	1.54	2	1	52.3	3.3	411 °C	362	12.0	13.9		

Glass type	Density ρ in g/cm³	P_d	n_d	Bubble class	Chemical resistance FR	Chemical resistance SR	Chemical resistance AR	T_g	$HK_{[0.1/20]}$	CTE in 10^{-6}/K −30 °C/+70 °C	CTE in 10^{-6}/K +20 °C/+300 °C	T_K in nm/K	Sensitivity*
BG61	2.81	0.915	1.53	2	1	52.3	3.3	402 °C	363	11.9	13.9		
BG62	2.85	0.914	1.54	2	1	52.3	3.3	410 °C	368	11.9	13.6		
BG63	2.79	0.915	1.53	2	1	52.3	3.3	416 °C	362	11.9	13.9		
BG64	2.78	0.916	1.53	2	1	52.3	3.3	417 °C	371	12.0	13.8		
BG66	2.85	0.914	1.54	0	0	52.3	3.3	411 °C	373	11.8	13.7		
BG67	2.85	0.913	1.54	2	1	52.3	3.3	390 °C	364	11.8	13.7		
S8022	2.77	0.910	1.56	1	0	4.0	3.0	453 °C	–	7.8	8.9		
S8023	2.75	0.913	1.54	1	0	4.0	3.0	444 °C	–	–	9.7**		
VG9	2.87	0.911	1.55	1	0	1.0	1.0	451 °C	449	9.2	10.6		
VG20	2.85	0.913	1.54	2	1	52.3	3.3	390 °C	364	11.8	13.7		
BG36	3.59	0.877	1.69	3	1	52.2	1.2	657 °C	701	6.1	7.2		
S8806A	3.50	0.877	1.69	–	–	–	–	645 °C	–	–	7.2		–
S8851	3.58	0.880	1.68	2	–	–	–	659 °C	–	–	7.2		–
S8008G	2.78	0.912	1.55	0	0	1.0	1.0	480 °C	569	7.6	9.0		–
S8802	2.70	0.915	1.53	0	0	1.0	1.0	510 °C	–	–	10.8		–
S8808	2.91	0.906	1.57	0	2	5.4	1.0	476 °C	–	–	13.3		–

Glass type	Density ρ in g/cm³	P_d	n_d	Bubble class	Chemical resistance			T_g	$HK_{[0.1/20]}$	CTE in 10^{-6}/K		T_K in nm/K	Sensitivity*
					FR	SR	AR			−30 °C/+70 °C	+20 °C/+300 °C		
S8809	2.91	0.921	1.57	–	–	–	–	459 °C	–	–	11.9		–
S7000	2.83	0.908	1.56	–	1	1.2	1.0	452 °C	–	–	11.1		–
S7005	2.88	0.908	1.56	–	–	–	–	452 °C	–	–	11.5		–
S7010N	2.88	0.909	1.56	–	1	1.2	1.0	452 °C	–	–	11.5		–
GG395	2.55	0.918	1.52	3	0	1.0	1.0	538 °C	409	7.8	9.0	0.07	
GG400	2.55	0.918	1.52	3	0	1.0	1.0	537 °C	463	7.9	9.1	0.07	
GG420	2.55	0.918	1.52	3	0	1.0	1.0	535 °C	503	7.8	9.0	0.07	
GG435	2.55	0.918	1.52	3	0	1.0	1.0	537 °C	449	7.8	9.1	0.08	
GG455	2.56	0.918	1.52	3	0	1.0	1.0	529 °C	445	8.2	9.5	0.09	
GG475	2.56	0.918	1.52	3	0	1.0	1.0	531 °C	451	8.2	9.4	0.09	
GG495	2.56	0.917	1.52	3	0	1.0	1.0	535 °C	501	8.1	9.4	0.10	
OG515	2.56	0.921	1.51	3	0	1.0	1.0	509 °C	455	7.9	9.0	0.11	
OG530	2.56	0.921	1.51	3	0	1.0	1.0	506 °C	450	7.9	9.0	0.11	
OG550	2.56	0.917	1.51	3	0	1.0	1.0	507 °C	462	7.9	9.0	0.12	
OG570	2.56	0.921	1.51	3	0	1.0	1.0	510 °C	455	7.9	9.0	0.12	
OG590	2.56	0.921	1.51	3	0	1.0	1.0	506 °C	448	7.9	9.0	0.13	

Glass type	Density ρ in g/cm^3	P_d	n_d	Bubble class	Chemical resistance FR	SR	AR	T_g	$HK_{[0.1/20]}$	CTE in $10^{-6}/K$ −30 °C/+70 °C	+20 °C/+300 °C	T_K in nm/K	Sensitivity*
RG610	2.65	0.920	1.51	3	0	1.0	1.0	520 °C	448	8.0	9.2	0.14	
RG630	2.65	0.918	1.52	3	0	1.0	1.0	527 °C	456	8.0	9.2	0.14	
RG645	2.65	0.918	1.52	3	0	1.0	1.0	519 °C	456	8.0	9.2	0.16	
RG665	2.77	0.918	1.52	3	0	1.0	1.0	527 °C	453	8.1	9.4	0.17	
RG695	2.76	0.915	1.53	3	0	1.0	1.0	532 °C	459	8.1	9.4	0.18	
RG715	2.76	0.914	1.54	3	0	1.0	1.0	532 °C	545	8.1	9.4	0.18	
RG780	2.94	0.908	1.56	3	5	53.4	1.3	552 °C	–	9.5	10.5	0.22	
RG830	2.94	0.909	1.56	3	5	53.4	1.3	554 °C	436	9.5	10.5	0.23	
RG850	2.93	0.909	1.56	3	5	53.4	1.3	554 °C	441	9.5	10.5	0.24	
RG9	2.58	0.918	1.52	3	0	1.0	1.0	519 °C	459	7.9	9.0	0.06	
RG905	2.54	0.921	1.51	3	0	1.0	1.0	481 °C	438	8.8	10.1		
RG1000	2.73	0.913	1.54	3	0	1.0	1.0	476 °C	460	9.0	10.3	0.41	
NG1	2.48	0.918	1.52	2	1	2.2	1.0	461 °C	418	6.5	7.0		
NG3	2.44	0.921	1.51	2	1	2.2	1.0	462 °C	443	6.5	7.3		
NG4	2.42	0.921	1.51	2	1	2.2	1.0	470 °C	423	6.5	7.1		
NG5	2.42	0.923	1.50	2	1	3.2	2.0	474 °C	435	6.6	7.1		
NG9	2.44	0.921	1.51	2	1	3.2	2.0	469 °C	420	6.5	7.0		
NG11	2.41	0.923	1.50	2	1	3.4	2.0	481 °C	460	6.7	7.2		

Glass type	Density ρ in g/cm³	P_d	n_d	Bubble class	Chemical resistance			T_g	$HK_{[0.1/20]}$	CTE in 10^{-6}/K		T_K in nm/K	Sensitivity*
					FR	SR	AR			−30 °C/ +70 °C	+20 °C/ +300 °C		
N-WG205	2.22	0.929	1.48	–	–	–	–	440°C	–	–	4.1		
N-WG280	2.51	0.918	1.52	1	0	1.0	2.0	558 °C	610	7.1	8.4	0.06	
N-WG295	2.51	0.918	1.52	1	0	1.0	2.0	565 °C	610	7.2	8.4	0.06	
N-WG305	2.51	0.918	1.52	1	0	1.0	2.0	562 °C	610	7.1	8.4	0.06	
N-WG320	2.51	0.918	1.54	1	0	1.0	2.0	563 °C	610	7.1	8.4	0.06	
N-WG360***	2.69	0.917	1.53	–	0	1.0	2.0	522 °C	474	7.8	8.9		–
KG1	2.52	0.918	1.51	3	0	2.0	3.0	599 °C	456	5.3	6.1		
KG2	2.52	0.921	1.51	3	0	2.0	3.0	605 °C	444	5.4	6.3		
KG3	2.52	0.919	1.51	3	0	2.0	4.0	581 °C	442	5.3	6.1		
KG5	2.53	0.921	1.51	3	0	3.0	4.0	565 °C	435	5.4	6.2		

Table 10.1: Physical and chemical properties (for reference only)

* Resistance against humidity and solarization properties (see Sections 5.5 and 5.6 of "Part I · Optical Filter Glass – Description")
"–" means no data exists.

** for +20 °C/+200 °C

*** N-WG360 and S8003N are identical

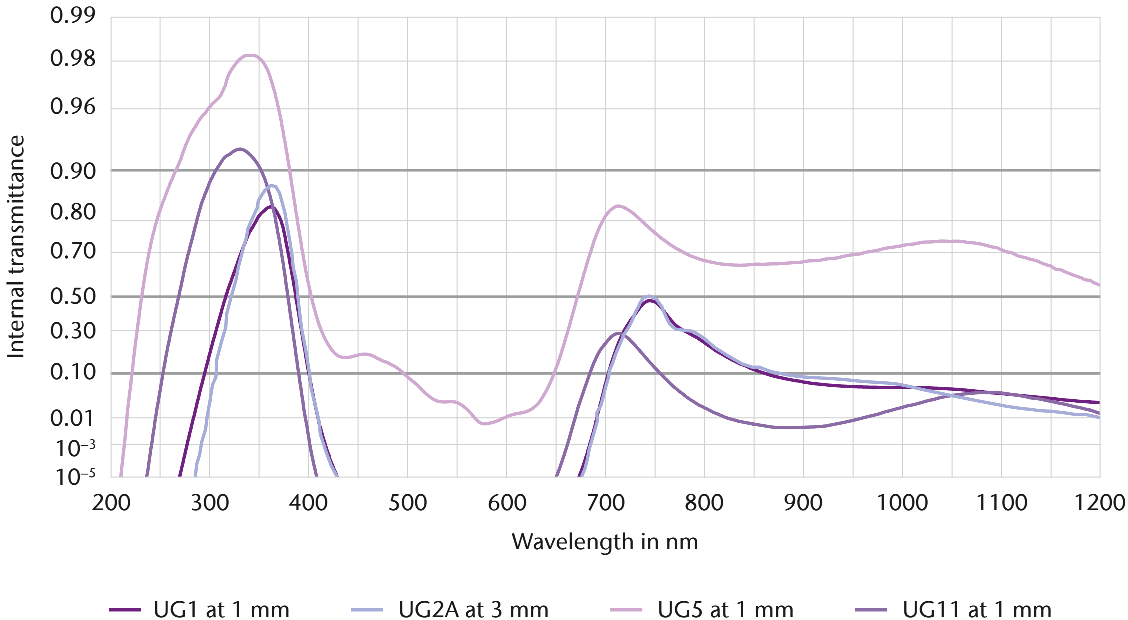
11 Internal transmittance graphs

The internal transmittance graphs are to be understood as typical curves for information only. The graphs of this section use a diabatic scale for the ordinate. Additional information is contained in the data sheets

The data sheets contain additional information regarding colorimetric evaluations.

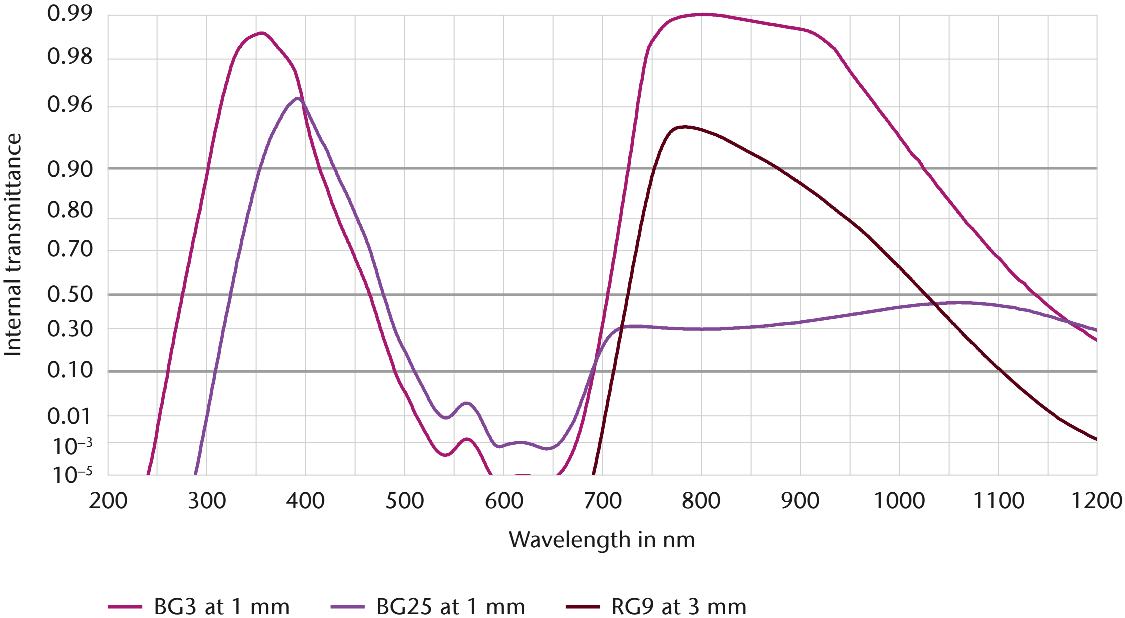
UV bandpass filter UG glass types

Figure 11.1



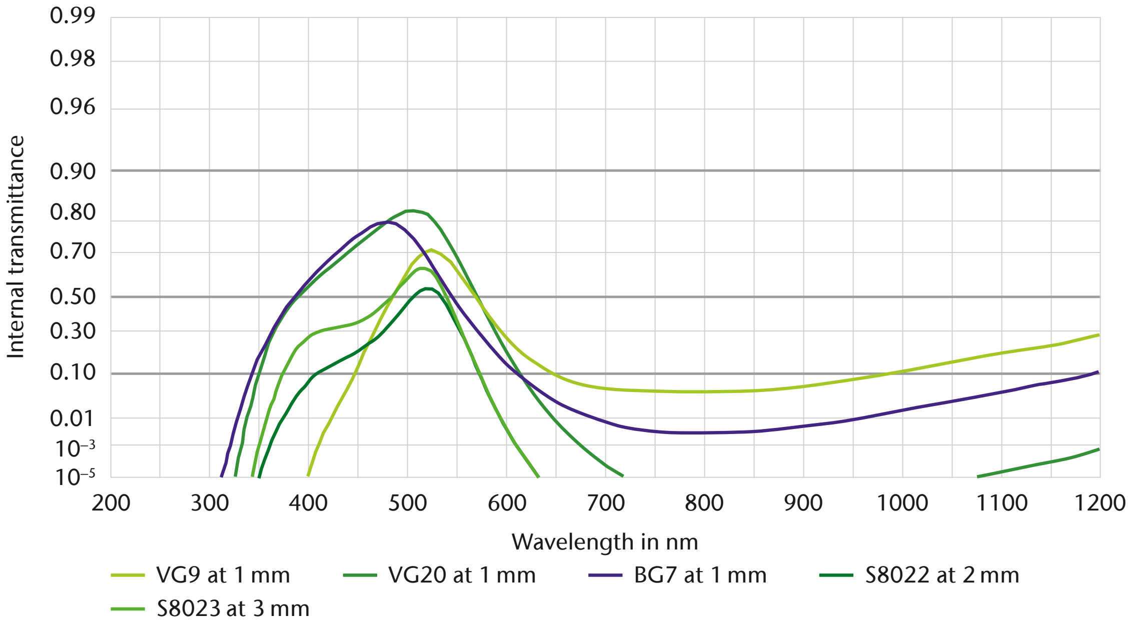
Bandpass filter (UV blue) BG, RG glass types

Figure 11.2



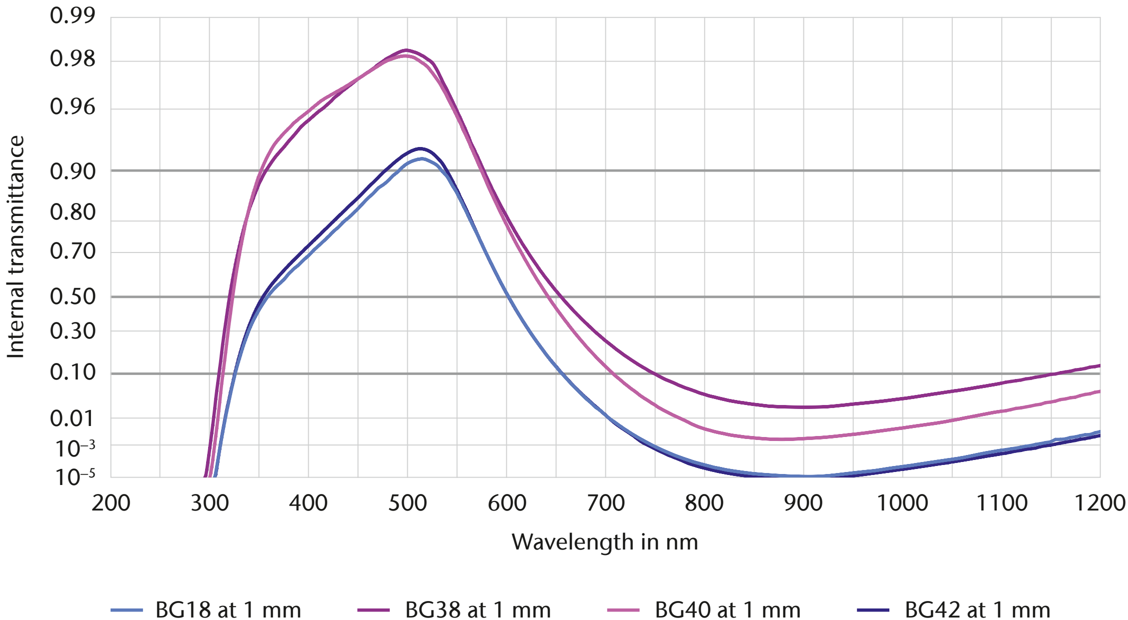
Bandpass filter (green) BG, VG and S glass types

Figure 11.3



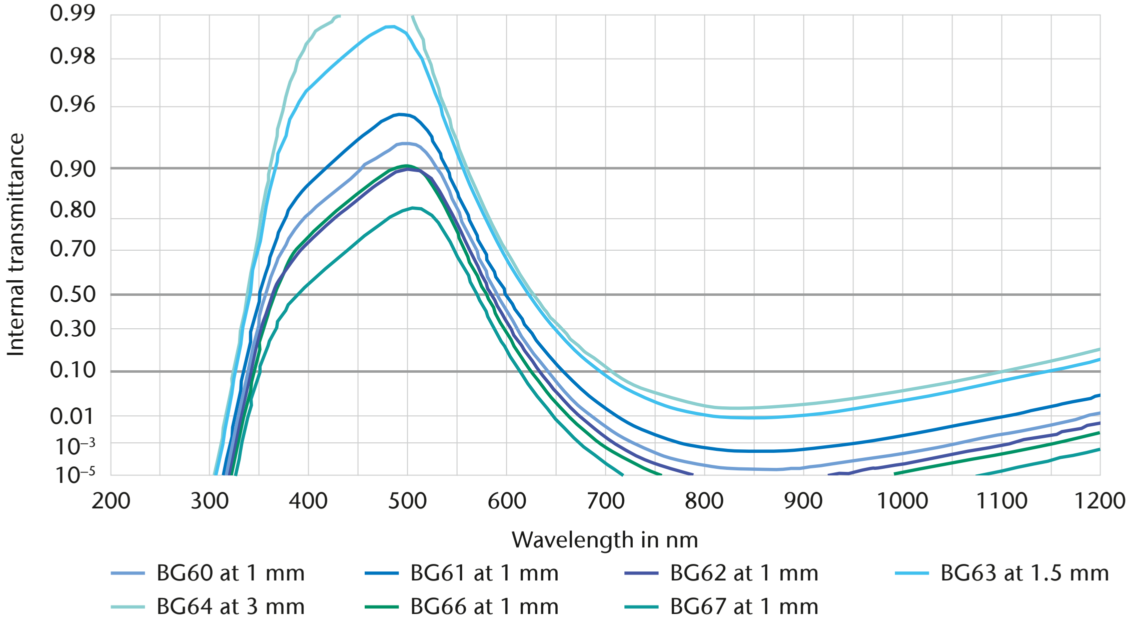
NIR cut filter 1 BG glass types

Figure 11.4



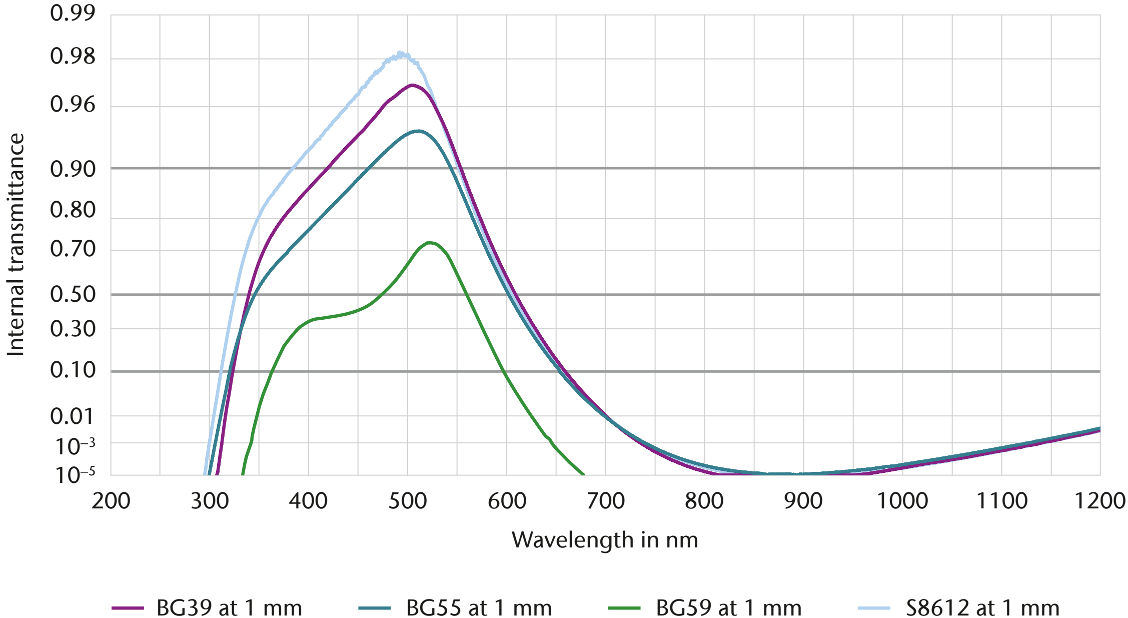
NIR cut filter 2 BG glass types

Figure 11.5



NIR cut filter 3 BG and S glass types

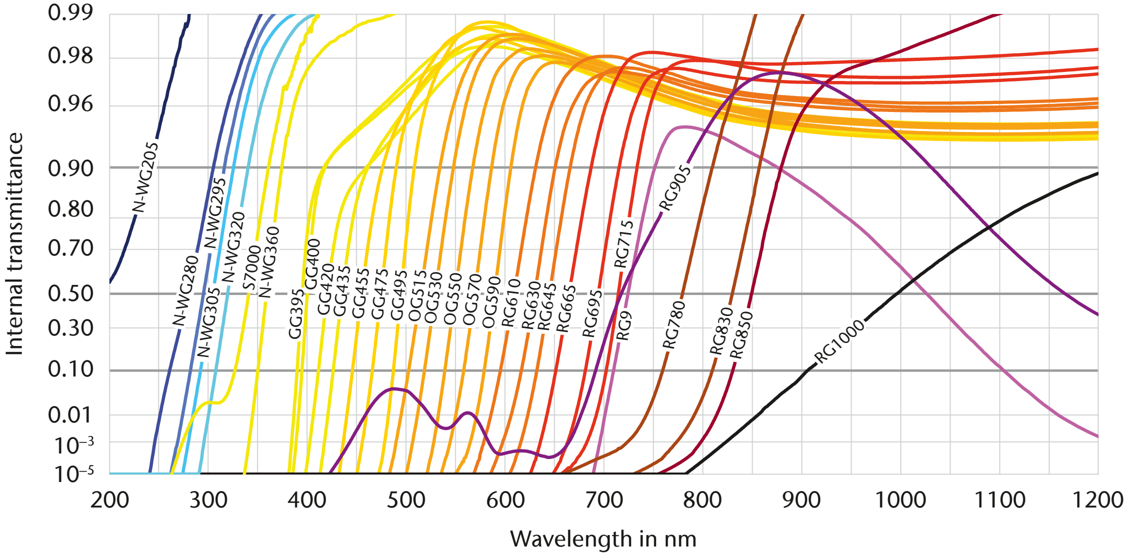
Figure 11.6



Longpass filter

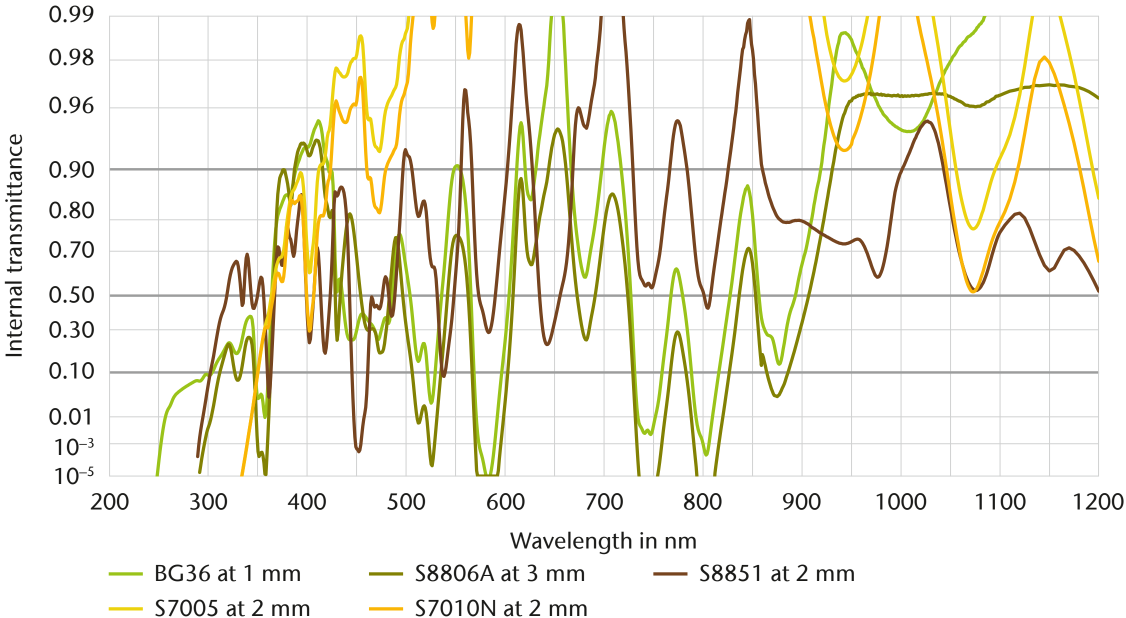
Figure 11.7

N-WG glass types with glass thickness 2 mm, GG, OG, RG glass types with glass thickness 3 mm, RG905 with glass thickness 4 mm



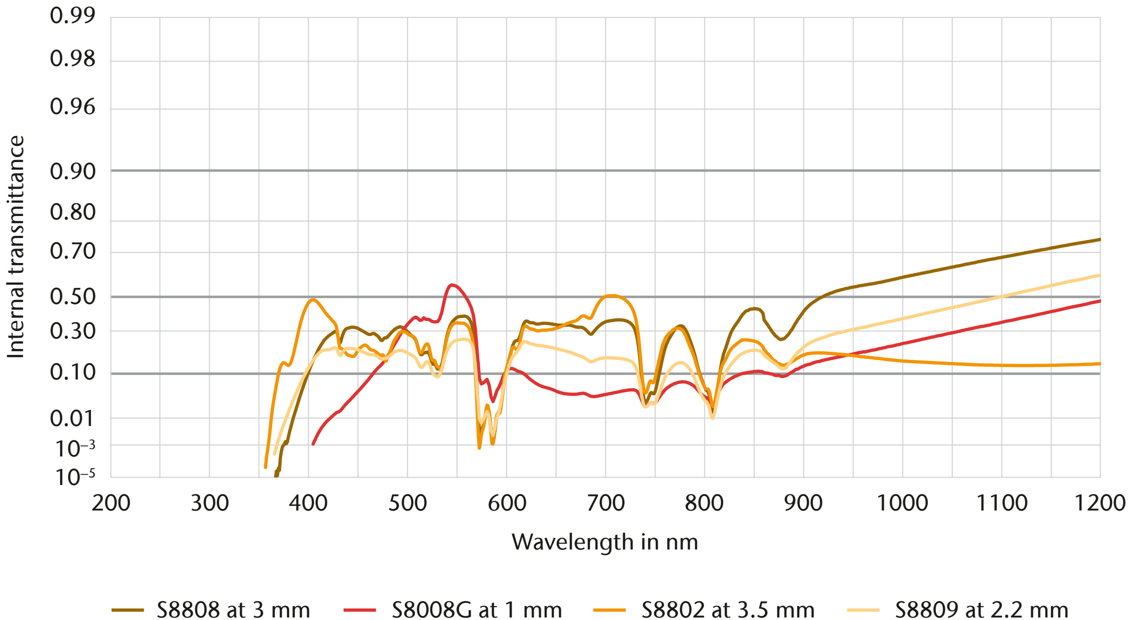
Multi-bandpass filter BG and S glass types

Figure 11.8



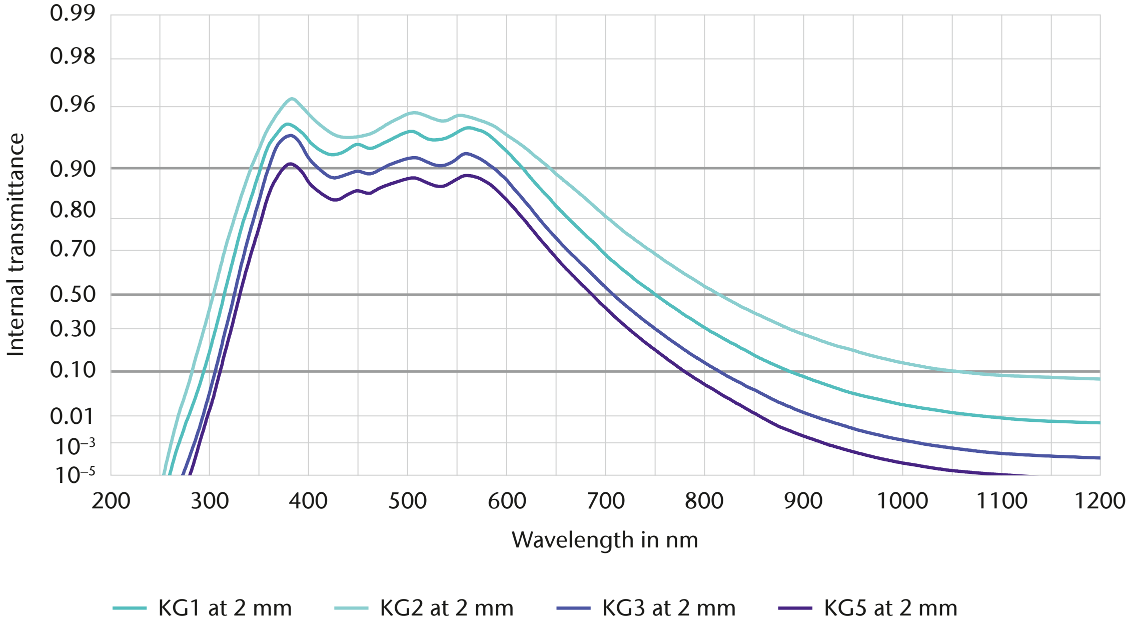
Contrast enhancement filter S glass types

Figure 11.9



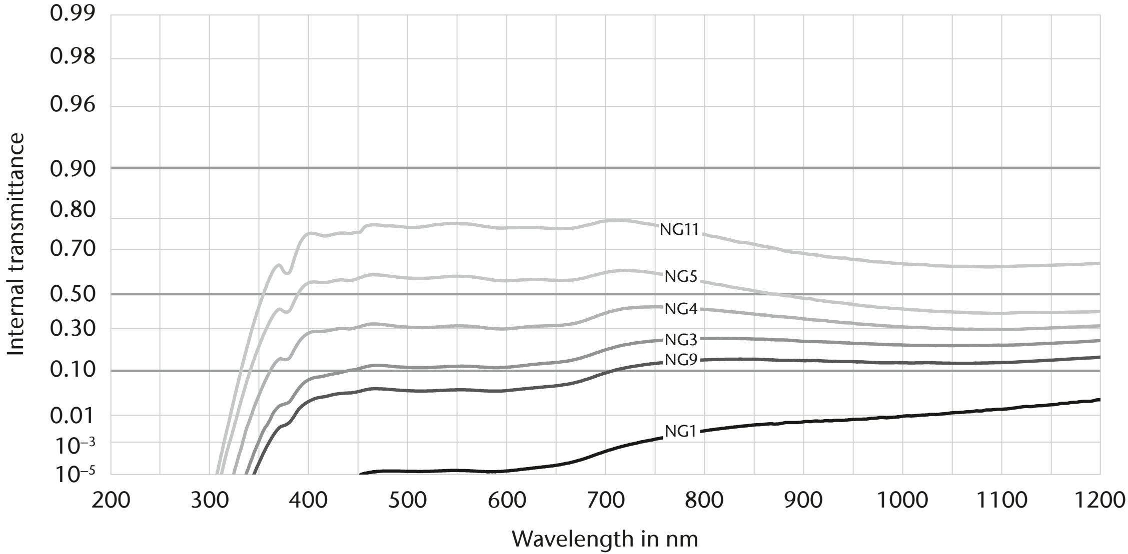
Shortpass filter – Heat protection glass KG glass types

Figure 11.10



Neutral density filter NG glass types

Figure 11.11



Glass thickness 1 mm

Filter glass combinations for color measurement

Figure 11.12

Filter SFK100A for the spectral value functions $\bar{x}(\lambda)$ and $\bar{z}(\lambda)$ of the 2° standard observer according to CIE 1931, see Chapter 3.9.2

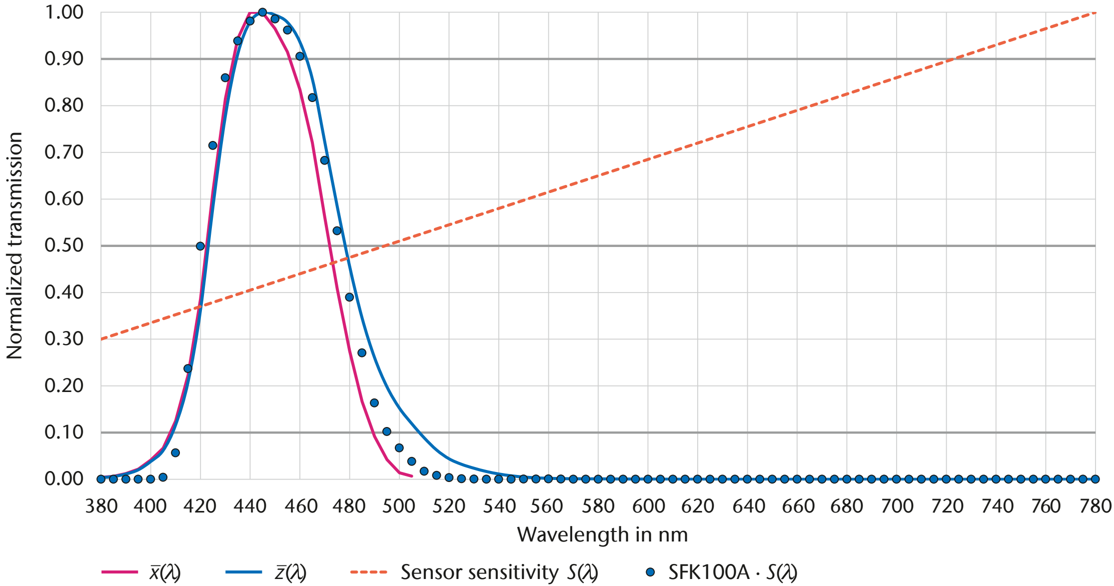


Figure 11.13

Filter SFK101B for the spectral value function $\bar{y}(\lambda)$ of the 2° standard observer according to CIE 1931, see Chapter 3.9.2

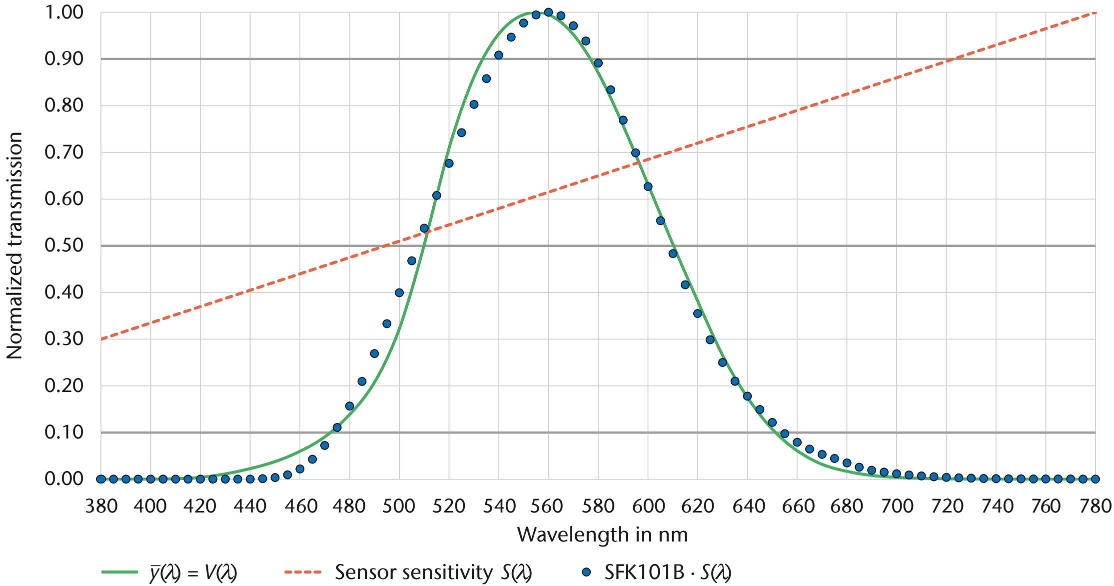
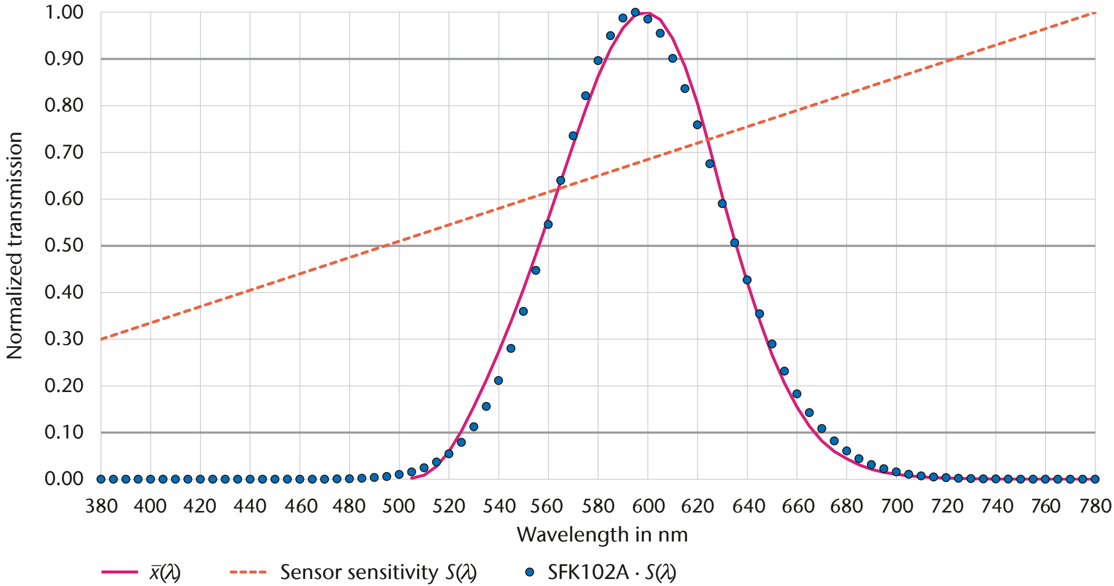


Figure 11.14

Filter SFK102A for the spectral value function $\bar{x}(\lambda)$ of the 2° standard observer according to CIE 1931, see Chapter 3.9.2



12 Tolerances for polished filters

We offer polished filters in different dimensions and optical surface quality.

12.1 Dimensions

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

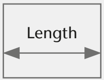
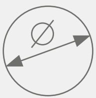
	Edge length	Minimum thickness		Chamfer
		Premium	Standard	
Rectangular shape 	≤ 300 ± 0.2	1.0 ± 0.1	1.5 ± 0.2	0.1 ~ 0.5
	≤ 120 ± 0.1	0.4 ± 0.1	1.0 ± 0.1	
	≤ 100 ± 0.1	0.4 ± 0.05	0.7 ± 0.1	
	≤ 50 ± 0.1	0.25 ± 0.03	0.5 ± 0.05	
	Diameter	**Minimum thickness**		**Chamfer**
		Premium	**Standard**	
Disc shape 	≤ Ø 300 ± 0.5	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 request (min Ø 4 mm).			

Table 12.1: Minimum thicknesses as a function of size. All dimensions in mm.

12.2 Polished surfaces

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

	Super	Premium	Standard
ISO 10110-7	5/ 3 x 0.1	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'

Table 12.2: Surface quality of polished filters in standard filter size (diagonal = 75 mm)

12.3 Optical quality

For most filter glasses, the wavefront error can be specified according to ISO 10110-14.

	Premium	Standard
13/	1 (0.25)	2 (1)

Table 12.3: Wavefront error for 90 % of the polished area

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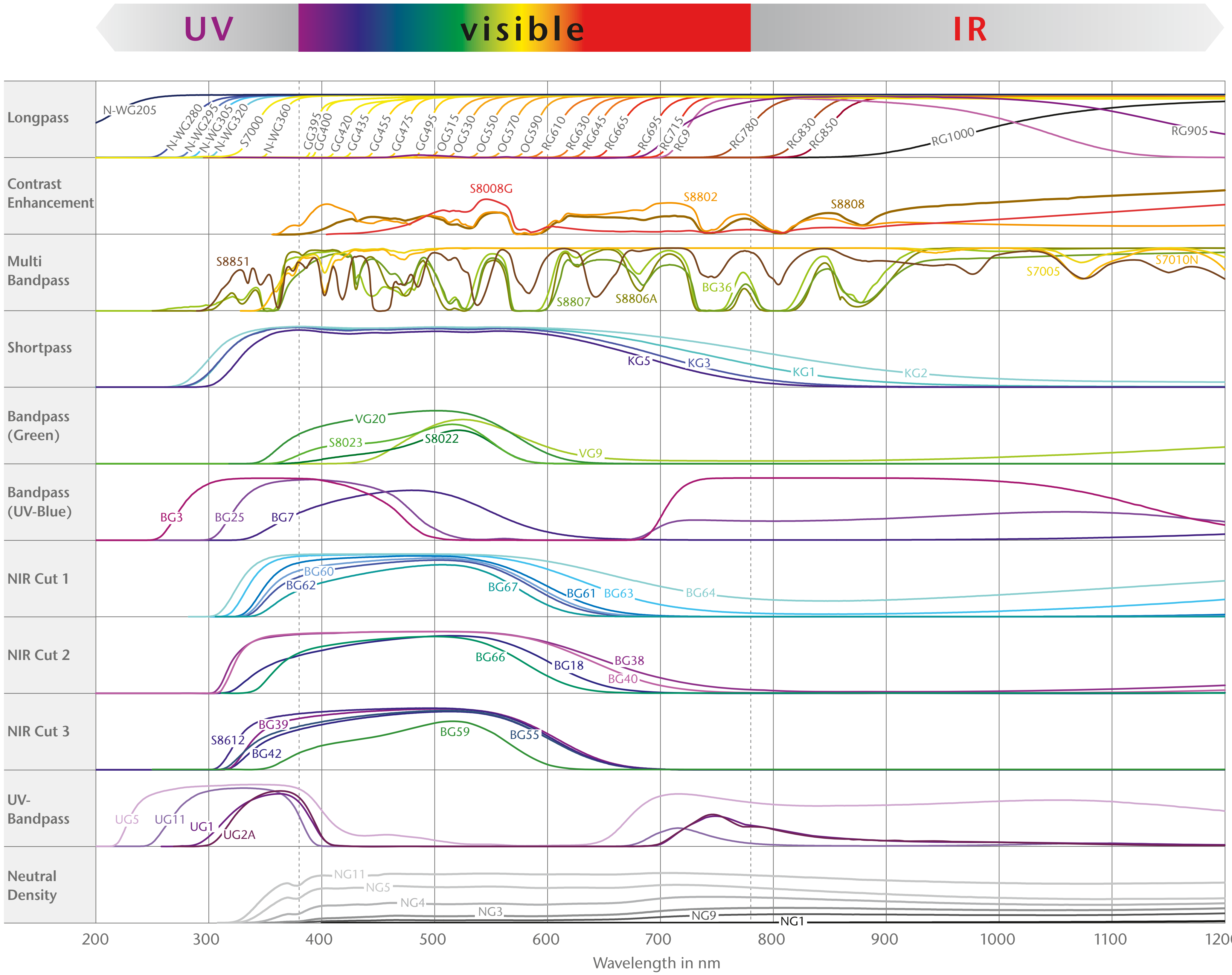
Optical filter glass – internal transmittance



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