SCHOTT
glass made of ideas

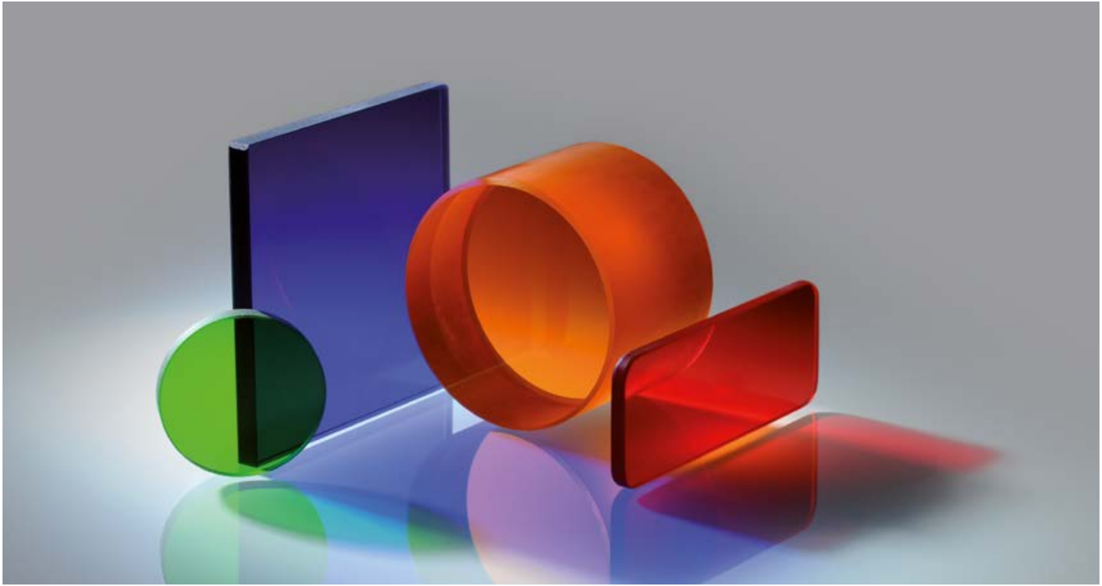
Optical Filter Glass 2020

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 technology 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 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.



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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 100 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 60 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
- Manufacture of complex glass types: high-quality surfaces, extremely thin, small tolerances
- In-house optical and protection coating capabilities
- Ability to accommodate special requirements via close collaboration and development efforts between customers and the SCHOTT application engineering team
- All colored filter glass types can be used as substrates for thin film coating in the manufacture of interference filters. Thus, specific advantages (absorption properties of a colored filter glass and the reflection properties of interference coatings) can be combined into one optical filter.

SCHOTT's optical filter glass portfolio is the product line of choice for system designers and optical engineers and is being constantly updated, reflecting market needs. While building on its capabilities, SCHOTT has also continuously expanded its optical filter glass portfolio. Thus, it now contains the special bandpass filters UG2A, BG57, BG66, and BG67 for UV and visible applications.

SCHOTT's optical filters are described in two parts whereby "Part I – 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 "Part II – Properties" covers additional technical information.

If any information not covered in this catalog 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 needs, as we believe that close relationships with customers is the key to success.

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 was 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 catalog replaces all previous publications.

January 2020

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1 Introduction

1.1 General information on listed data

All data listed in this catalog without tolerances are to be understood as reference values. Only those values listed in chapter 2 in the "Properties" part, 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" 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 datasheets and the filter calculation program can be easily accessed at www.schott.com/advanced_optics, 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, more accurate reference values can be given, and guaranteed values can be adapted, when possible, to meet your requirements.

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 is done strictly following established safety procedures and fulfills requirements on material compliance.

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 the flame retardants PBB and PBDE. 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 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 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 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 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 for a full spectral solution that meets your requirements. 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 on our website which is updated every year.

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 appear colored only 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 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*

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).

* NIR as defined in ISO 4007 is the IR-A wavelength range from 780 nm to 1400 nm.

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 transmittance is controlled only for the wavelengths, which are mentioned in the section "spectral values guaranteed" 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. Outside this region, variations might however be much larger. The colloidally colored glasses also exhibit deviations within a melt due to technically unavoidable temperature gradients during the striking process.

In the “Properties” part, 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 variations 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 optical filter glasses. The terms and definitions are in accordance with DIN 58131.

In addition, the relevant optical features of 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(λ). 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 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(λ)). 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 constraints of incoherent radiation and perpendicular incidence, and considering multiple reflections, **equation 1** applies.

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

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

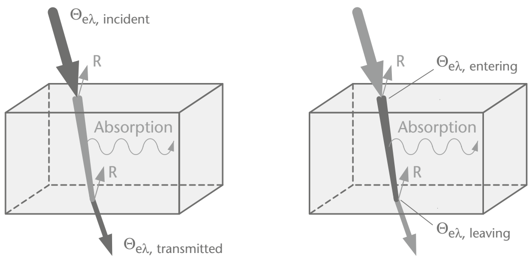


Fig. 3.1
Definition of spectral transmittance (left) and internal spectral transmittance (right).

Definition of **spectral transmittance**:

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

Spectral transmittance $\tau(\lambda)$ in **equation 2** is the ratio of the transmitted (energetic) spectral flux $\Theta_{e\lambda,transmitted}$ to the incident (energetic) spectral flux $\Theta_{e\lambda,incident}$. 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 measured easily. 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:**

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

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. Internal transmittance $\tau_i(\lambda)$ describes the transmittance of the absorbing filter glass without considering reflection losses. However, internal transmittance cannot be measured directly. There are two formulas for converting spectral internal transmittance into transmittance and vice versa:

Using R: $\tau = \frac{(1-R)^2\tau_i}{1-\tau_i^2 R^2}$ 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(λ):

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

Equation 4 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.

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

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

6
$$\tau_{d_1}(\lambda) = P(\lambda) \cdot \tau_{i,d_2}(\lambda)^{d_1/d_2}$$

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

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

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

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

3.4.2 Spectral extinction (absorbance)

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

3.4.3 Spectral diabatie

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

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

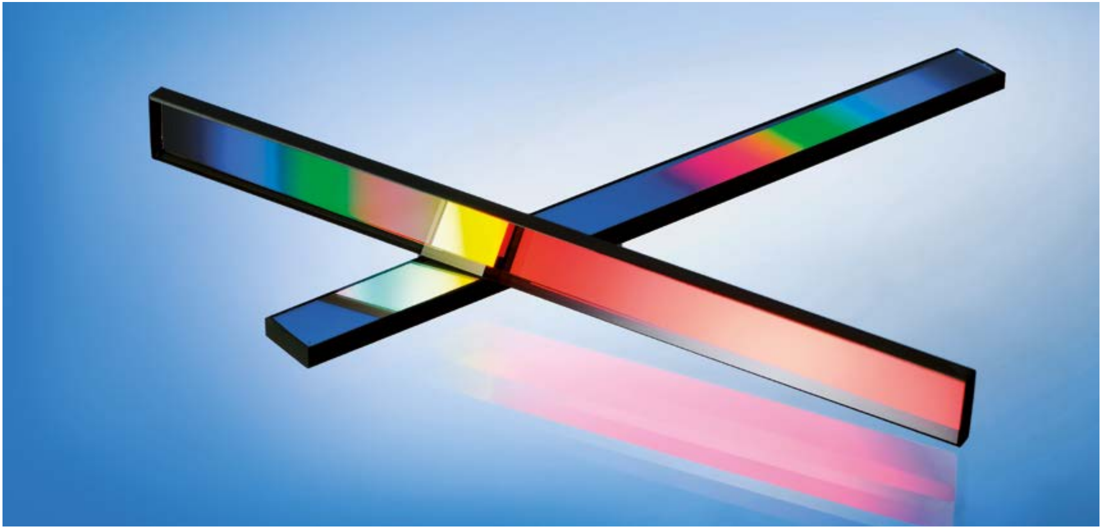
11 $$\tau_{v,D65} = 100\,\% \; \frac{\int_{\lambda = 380\text{ nm}}^{780\text{ nm}} \tau(\lambda)\, S_{D65}(\lambda)\, V(\lambda)\, d\lambda}{\int_{\lambda = 380\text{ nm}}^{780\text{ nm}} S_{D65}(\lambda)\, V(\lambda)\, d\lambda}$$

Luminous transmittance (according to 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 graphs

The $\tau_i(\lambda)$ values 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 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 long-pass filter is characterized by the fact that a range of low transmission (blocking range) in the short wavelength range is joined to an area of high transmission (pass band) in the long wavelength range (**see figure 3.2**).

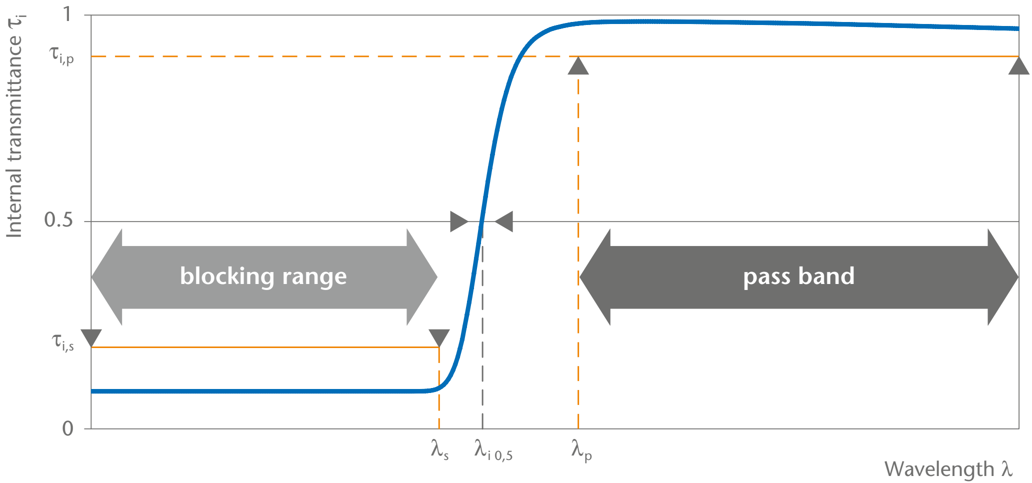


Fig. 3.2
Longpass filter

The important properties applicable to optical filter glasses:

$\lambda_{i\ 0,5}$: 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.

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 the pass band and blocking range of a longpass filter is much steeper than the slope of a shortpass filter.

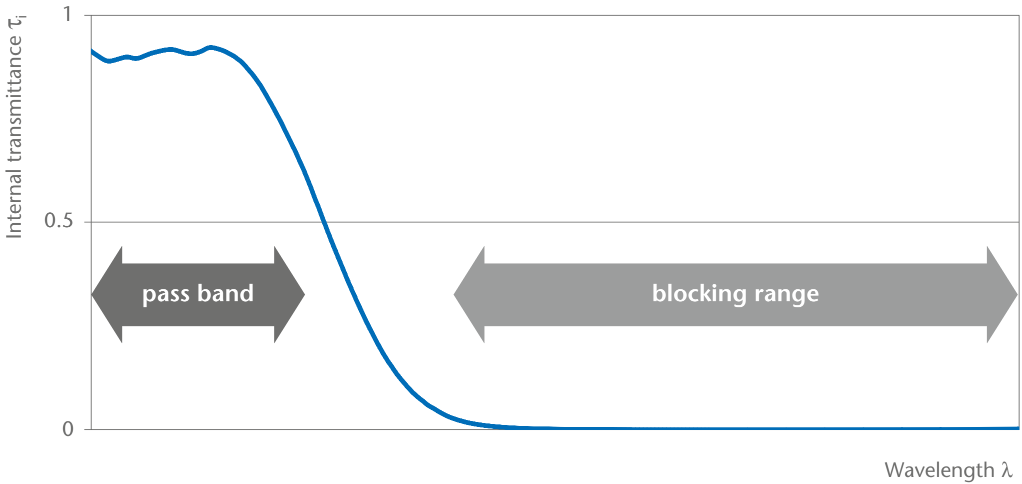


Fig. 3.3
Shortpass filter

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 ranges with low transmission (blocking ranges).

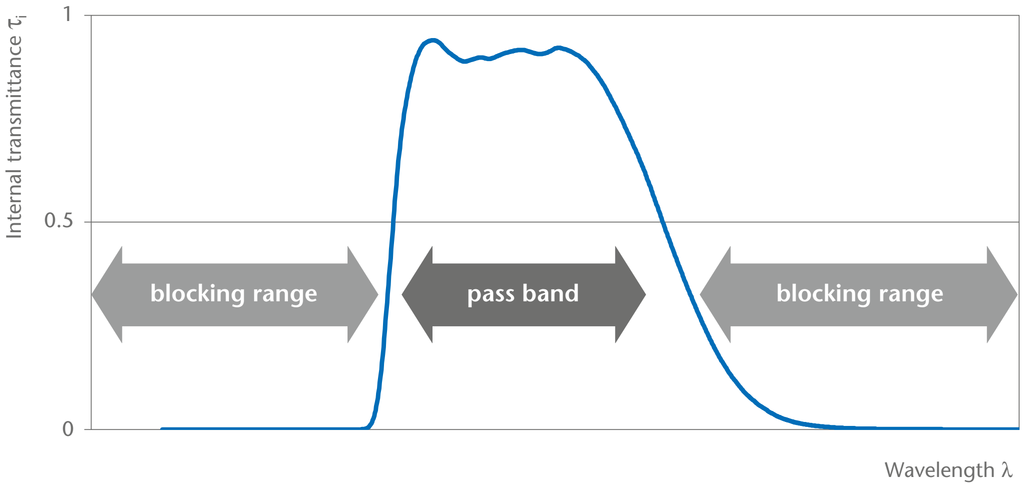


Fig. 3.4
Bandpass filter

3.6.4 Neutral density filters

Neutral density filters exhibit nearly constant spectral transmittance in the range of 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.

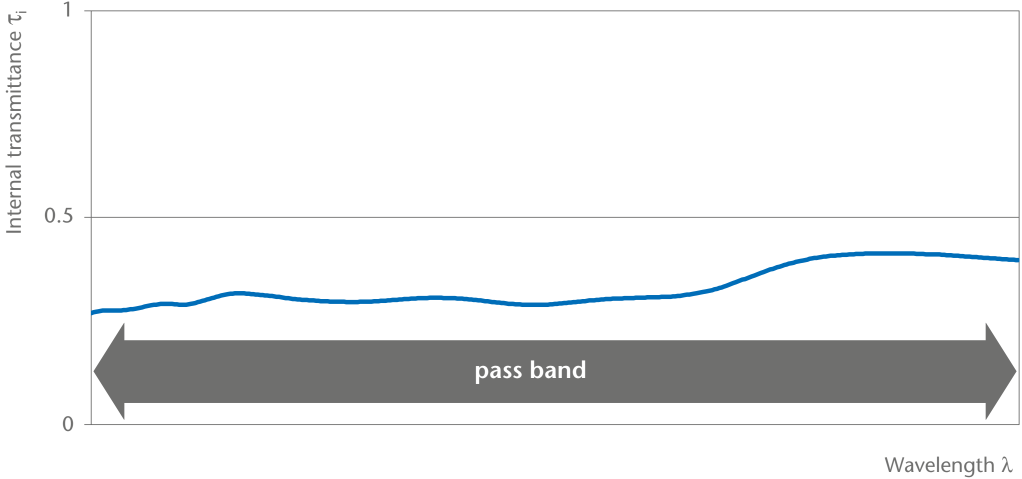


Fig. 3.5
Neutral density filter

3.6.5 Overview of transmittance properties

The figure in the back pocket of this booklet depicts the transmittance properties of all our optical glass filters. In order to give a clear overview, the graphs are sorted into eleven 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" part, the temperature coefficient of the edge wavelength $\Delta\lambda_c/\Delta T$ [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 of practical interest only when 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 problems in most cases.

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 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 3.6**): 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.

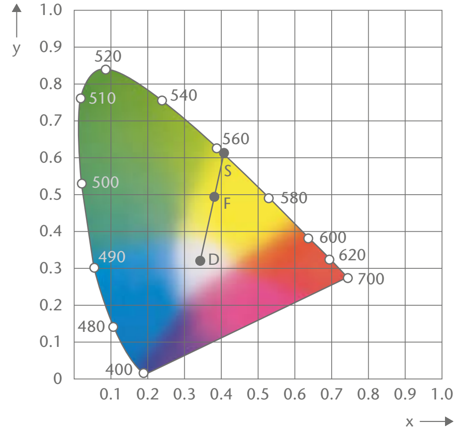


Fig. 3.6
The color of optical filter glasses according to the definition of CIE 1931
D: Color locus of the radiation source, for example D65
S: Point at which the extension $\overline{DF}$ intersects the spectrum locus at λ_d

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 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[1] x and y coordinates by way of the following formula:

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

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:

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

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

where:

u'_0 and v'_0 = 1976 UCS chromaticity coordinates of the center point of the specified color area

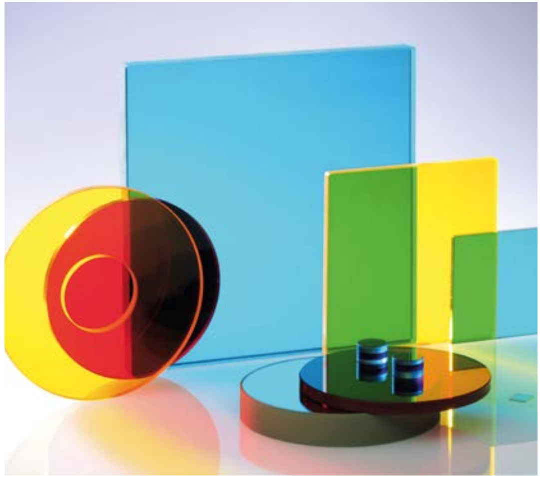
u' and v' = 1976 UCS chromaticity coordinates of the color locus of the illumination system (e.g. combination of filter and light source)

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 1 %.

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



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" part, 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/cm³]

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/cm³.

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

4.2 Knoop hardness

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 values listed 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 of order ±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 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.

4.4 Thermal toughening

In most cases, an absorbing optical filter glass is heated unevenly by 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 and especially between the center and the edges of the optical filter glass. This produces flexural stresses within the optical filter glass based on thermal expansion.

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

Thermal toughening is required to increase the breaking strength of optical filter glasses placed in front of intense light sources. 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" part.

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 to the glasses. Direct metal-to-glass contact must be avoided; insulating intermediate layers made of suitable materials are recommended.

4.5 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.

4.6 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" part.

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.

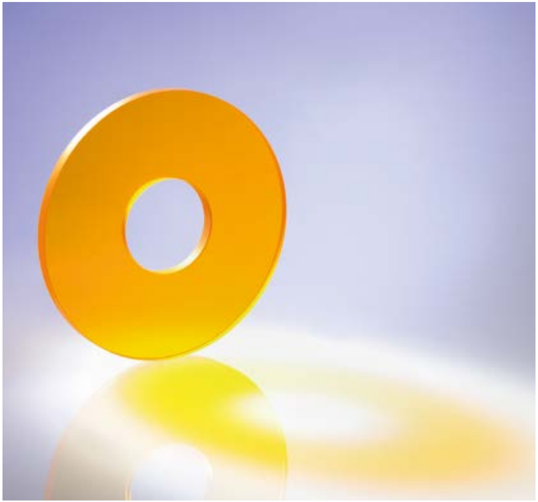
The stain resistance class is determined according to the following procedure: The plane polished glass sample to be tested is pressed onto a test cuvette, which has a spherical depression of max. 0.25 mm depth containing a few drops of test solution I or II.

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.

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 classifies the behavior of glass surfaces that come in contact with large quantities of acidic solutions (practical examples: perspiration, laminating substances, carbonated water, etc.).

Acid resistance is denoted by 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.

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 exhibits 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 with relative humidity, surface quality, and surface contamination also having an influence. Therefore, it is not possible to give an exact rating of sensitivity to warm humidity. With respect to this behavior, the color filter glasses are classified into four groups:

Group “resistant glasses”
No substantial surface change occurs in the 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.

Group “robust glasses” Symbol: 
Glass types marked with a closed umbrella withstand warm humidity testing at 60 °C and 90 % relative humidity for more than 48 hours.

Group “sensitive glasses” 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.

Group “delicate glasses” 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.

Strengthened filter glass with scratch-resistant coating.

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 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 for unpolished glass and polished optical filter components. The reason is that bubble classes for unpolished glasses are defined for a large volume of 100 cm³, while polished optical filter components are often much smaller. Therefore, it is not 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 the overall cross-sectional area of the bubbles in mm² relative to 100 cm³ 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 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	>0.03	≤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 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. 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 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 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 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.

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

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 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.

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 or contact a sales representative.

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

Longpass filters that are IR transmittant.

Optical Filter Glass

Part II – Properties

1 Optical filter glass: product line

1.1 Portfolio glasses

The color filter glass product line comprises of more than 69 optical filter glass types.

New optical filters such as UG2A, BG57, BG66, and BG67 have been developed recently.

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 commitment and our life cycle management, please see the annually updated positive list 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	WG280	OG515	KG1	NG1
UG2A	BG7	BG61	S8008G	N-WG295	OG530	KG2	NG3
UG5	BG18	BG62	S8802	N-WG305	OG550	KG3	NG4
UG11	BG25	BG63	S8806A	N-WG320	OG570	KG5	NG5
		BG64	S8808	S8003N	OG590		NG9
	BG38	BG66		GG395			NG11
	BG39	BG67		GG400	RG610		
	BG40			GG420	RG630		
	BG42	S8612		GG435	RG645		
	BG55	S8022		GG455	RG665		
	BG57	S8023		GG475	RG695		
				GG495	RG715		
		VG9			RG780		
		VG20			RG830		
					RG850		
					RG9		
					RG1000		

Table 1.1: SCHOTT portfolio glasses: long-term availability

1.2 Inquiry glasses

The following glass types are melted on special request only:

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 1.2: Inquiry glasses that are made on request only

1.3 Data and tolerances

All data listed in this catalog without tolerances are to be understood as reference values. Only those values listed in chapter 2 of this "Properties" part 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.

2 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 repeatabilty 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

Filter glass type	Thickness	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 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)	≤ 0.50 (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)				
BG36	1 mm	≥ 0.90 (405)	≤ 0.42 (450)	≥ 0.90 (650)	≤ 0.01 (800)				
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)			

Filter glass type	Thickness	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])
BG57	1 mm	≥ 0.35 (405)	≥ 0.37 (430)	≥ 0.71 (514)	≥ 0.42 (565)	≤ 0.02 (633)	≤ 0.02 (1500)		
BG60	1	≥ 0.80 (405)	≥ 0.91 (514)	≥ 0.10 (633)	≤ 0.008 (694)	≤ 0.0015 (1060)			
BG61	1	≥ 0.84 (405)	≥ 0.93 (514)	≥ 0.18 (633)	≤ 0.03 (694)	≤ 0.008 (1060)			
BG62	1	≥ 0.73 (405)	≥ 0.89 (514)	≥ 0.08 (633)	≤ 0.005 (694)	≤ $5*10^{-4}$ (1060)			
BG63	1	≥ 0.95 (405)	≥ 0.96 (514)	≥ 0.50 (633)	≤ 0.25 (694)	≤ 0.16 (1060)			
BG64	1	≥ 0.99 (405)	≥ 0.99 (514)	≥ 0.72 (633)	≤ 0.55 (694)	≤ 0.45 (1060)			
BG66	1	≥ 0.815 (430)	≥ 0.89 (514)	≥ 0.615 (565)	≤ 0.0015 (694)	≤ $2*10^{-4}$ (1060)			
BG67	1	≥ 0.70 (450)	≥ 0.80 (500)	≥ 0.65 (550)	≤ 0.19 (600)				
VG9	1	≤ 0.21 (450)	≥ 0.67 (514)	≤ 0.15 (633)	≤ 0.07 (725)	≤ 0.18 (1060)			
VG20	1	≥ 0.75 (450)	≥ 0.83 (500)	≥ 0.65 (550)	≤ 0.19 (600)				
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)	≤ $1*10^{-4}$ (1060)	≤ 0.001 (2200)

Table 2.1: Spectral values guaranteed for shortpass and bandpass filters

Tolerances for NVIS filters

Filter glass type	Thickness	Photopic transmittance [%]		NVIS color according to MIL-STD-3009
		2100K	1500K	
S8022	2 mm	13.5 ± 1.5	9.0 ± 1.5	Green A
S8023	3 mm	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	τ_i (405 nm)	τ_i (546 nm)	τ_i (694 nm)
NG1	1 mm		$< 1 \cdot 10^{-4}$	
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 2.3: Spectral values guaranteed for neutral density filters

Tolerances and limit values for longpass filters

Filter glass type	Thickness	$\lambda_{i\,0,5}$ ($\tau_i = 0.50$) in nm	λ_s ($\tau_{is} \leq 1 \cdot 10^{-5}$) in nm	λ_{p1} (τ_{ip1}) in nm	λ_{p2} (τ_{ip2}) in nm
N-WG280	2 mm	280 ± 6	230	380 (0.99)	
N-WG295	2 mm	295 ± 6	250	400 (0.99)	
N-WG305	2 mm	305 ± 6	260	420 (0.99)	
N-WG320	2 mm	320 ± 6	280	470 (0.99)	
GG395	3 mm	395 ± 6	340	480 (0.92)	
GG400	3 mm	400 ± 6	340	480 (0.93)	
GG420	3 mm	420 ± 6	360	530 (0.93)	
GG435	3 mm	435 ± 6	370	520 (0.92)	
GG455	3 mm	455 ± 6	390	530 (0.92)	
GG475	3 mm	475 ± 6	410	550 (0.92)	
GG495	3 mm	495 ± 6	430	560 (0.92)	
OG515	3 mm	515 ± 6	440	580 (0.93)	
OG530	3 mm	530 ± 6	460	600 (0.93)	
OG550	3 mm	550 ± 6	480	620 (0.93)	
OG570	3 mm	570 ± 6	500	640 (0.93)	
OG590	3 mm	590 ± 6	510	660 (0.93)	

Filter glass type	Thickness	$\lambda_{i\,0,5}$ (τ_i = 0.50) in nm	λ_s ($\tau_{is} \leq 1 \cdot 10^{-5}$) in nm	λ_{p1} (τ_{ip1}) in nm	λ_{p2} (τ_{ip2}) in nm
RG610	3 mm	610 ± 6	530	690 (0.94)	
RG630	3 mm	630 ± 6	540	710 (0.94)	
RG645	3 mm	645 ± 6	560	720 (0.94)	
RG665	3 mm	665 ± 6	580	750 (0.96)	
RG695	3 mm	695 ± 6	610	780 (0.96)	
RG715	3 mm	715 ± 9	620	810 (0.96)	
RG780	3 mm	780 ± 9	610	900 (0.97)	
RG830	3 mm	830 ± 9	670	950 (0.97)	
RG850	3 mm	850 ± 9	700	950 (0.90)	1200 (0.97)
RG1000	3 mm	1000 ± 6	730	1300 (0.90)	

Table 2.4: Spectral values guaranteed for longpass filters

3 Optical filter glass: references values

The following data is for reference only. 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	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	Notes*
UG1	2.77	0.913	1.54	1	0	1.0	1.0	603 °C	482	7.9	8.9		
UG2A	2.60	0.918	1.52	2	0	1.0	1.3	484 °C	–	8.6	9.9		
UG5	2.85	0.914	1.54	2	0	3.0	2.0	462 °C	407	8.1	9.4		
UG11	2.92	0.908	1.56	2	0	3.0	2.2	545 °C	440	7.8	9.0		
BG3	2.55	0.921	1.51	1	0	1.0	1.0	478 °C	438	8.8	10.1		
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	8.8	10.2		
BG36	3.59	0.877	1.69	3	1	52.2	1.2	657 °C	701	6.1	7.2		
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	2	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		
BG50	2.61	0.916	1.53	1	0	2.0	2.0	452 °C	500	7.3	9.0		
BG55	2.65	0.914	1.54	2	0	2.0	2.0	453 °C	504	7.2	9.1		
BG57	2.81	0.911	1.55	0	0	5.2	3.0	411 °C	418	9.7	11.5		

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	Notes*
					FR	SR	AR			−30 °C/ +70 °C	+20 °C/ +300 °C		
BG60	2.83	0.914	1.54	2	1	52.3	3.3	411 °C	362	11.9	13.9		
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	11.9	13.8		
BG66	2.85	0.914	1.54	0	0	52.3	3.3	411 °C	373	11.7	13.7		
BG67	2.85	0.913	1.54	2	1	52.3	3.3	390 °C	364	11.7	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	9.1	10.6		
VG20	2.85	0.913	1.54	2	1	52.3	3.3	390 °C	364	11.7	13.7		
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	

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	Notes*
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	1.52	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	
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	
RG1000	2.73	0.913	1.54	3	0	1.0	1.0	476 °C	460	9.0	10.3	0.41	

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	Notes*
NG1	2.48	0.918	1.52	2	1	2.2	1.0	461	418	6.4	7.0		
NG3	2.44	0.921	1.51	2	1	2.2	1.0	462	443	6.5	7.3		
NG4	2.42	0.921	1.51	2	1	2.2	1.0	470	423	6.5	7.1		
NG5	2.42	0.923	1.50	2	1	3.2	2.0	474	435	6.6	7.1		
NG9	2.44	0.921	1.51	2	1	3.2	2.0	469	420	6.4	7.0		
NG11	2.41	0.923	1.50	2	1	3.4	2.0	481	460	6.6	7.2		
N-WG280	2.51	0.918	1.52	1	0	1.0	2.0	558	610	7.1	8.4	0.06	
N-WG295	2.51	0.918	1.52	1	0	1.0	2.0	565	610	7.2	8.4	0.06	
N-WG305	2.51	0.918	1.52	1	0	1.0	2.0	562	610	7.1	8.4	0.06	
N-WG320	2.51	0.918	1.52	1	0	1.0	2.0	563	610	7.1	8.4	0.06	
KG1	2.52	0.918	1.52	3	0	2.0	3.0	599	456	5.3	6.1		
KG2	2.52	0.921	1.51	3	0	2.0	3.0	605	444	5.4	6.3		
KG3	2.52	0.919	1.52	3	0	2.0	4.0	581	442	5.3	6.1		
KG5	2.53	0.921	1.51	3	0	3.0	4.0	565	435	5.4	6.2		

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

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

** $\alpha_{20/200°C}$

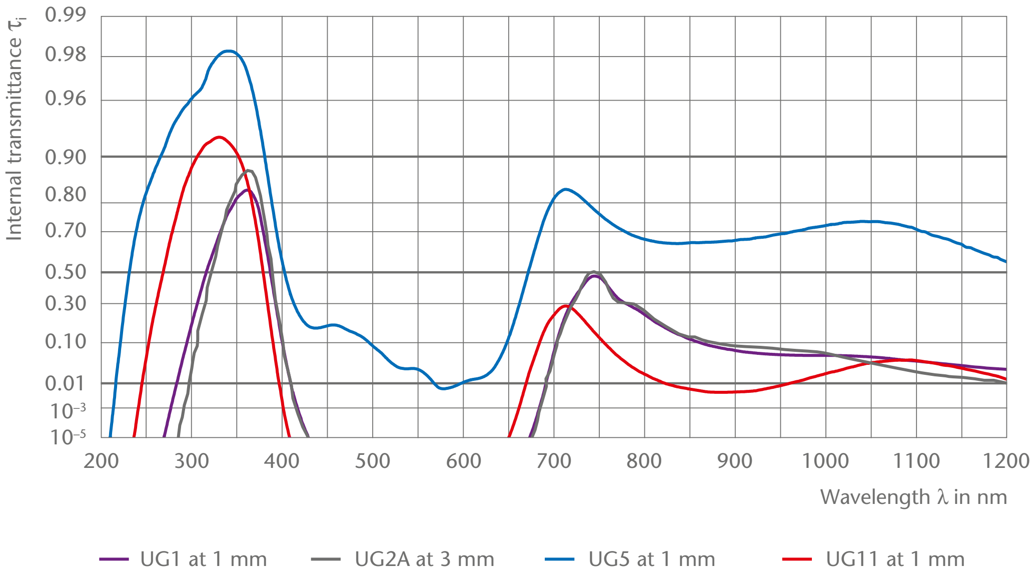
4 Internal transmittance graphs

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 abscissa. Additional information is contained in the data sheets.

The data sheets contain additional information regarding colorimetric evaluations.

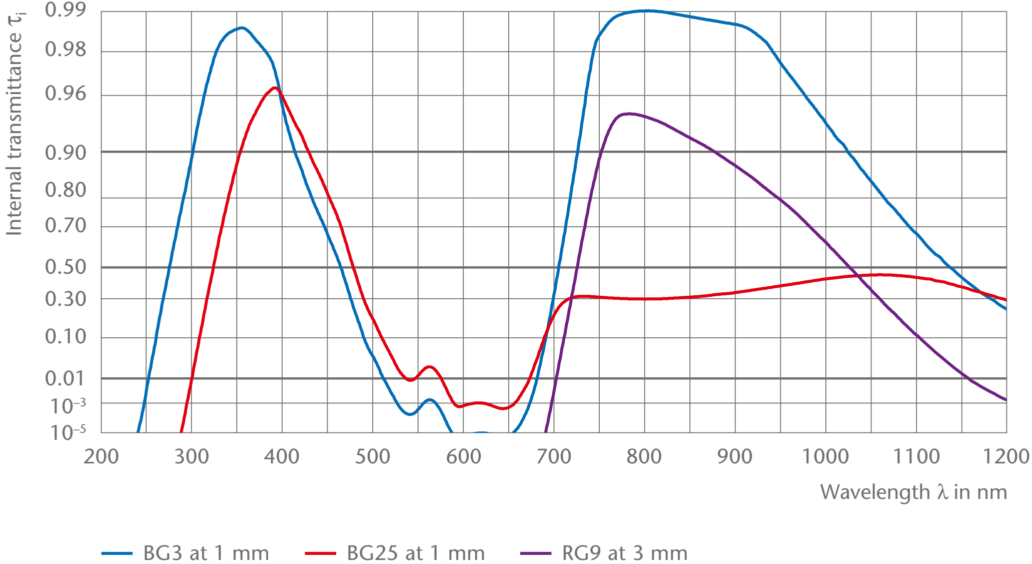
UV bandpass filter UG glass types

Fig. 4.1



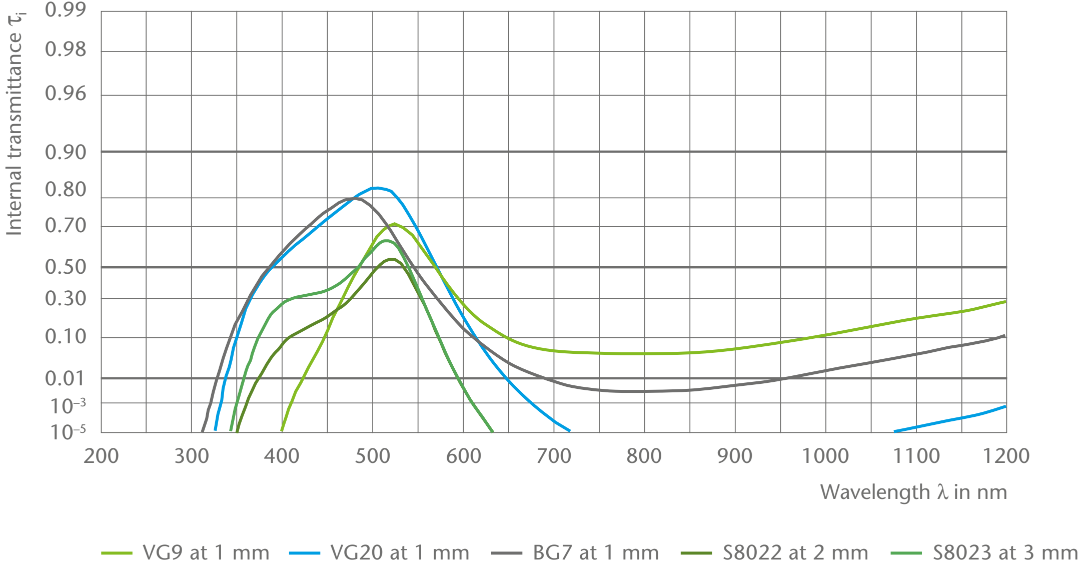
Bandpass filter BG, RG glass types

Fig. 4.2



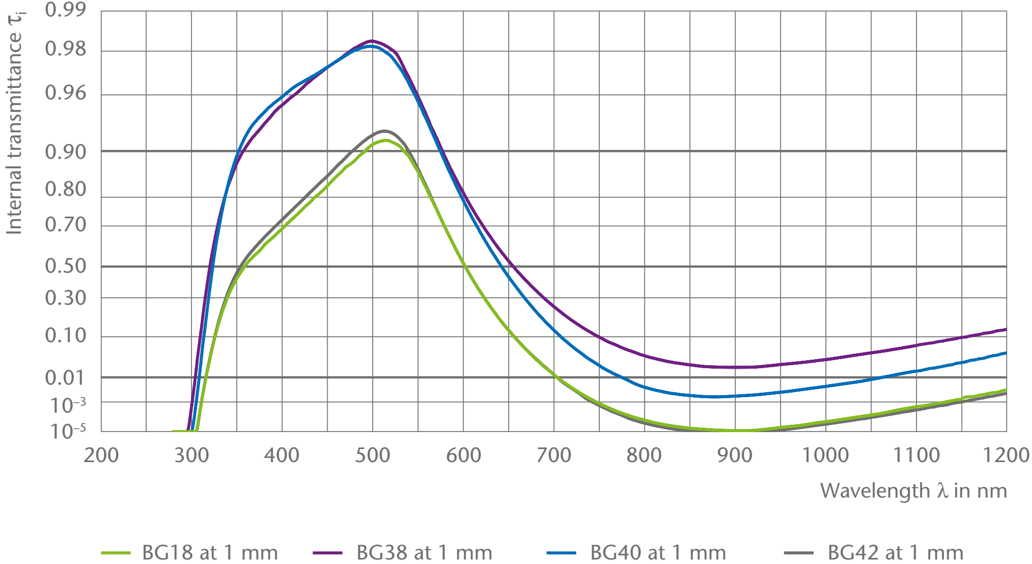
Bandpass filter BG, VG und S glass types

Fig. 4.3



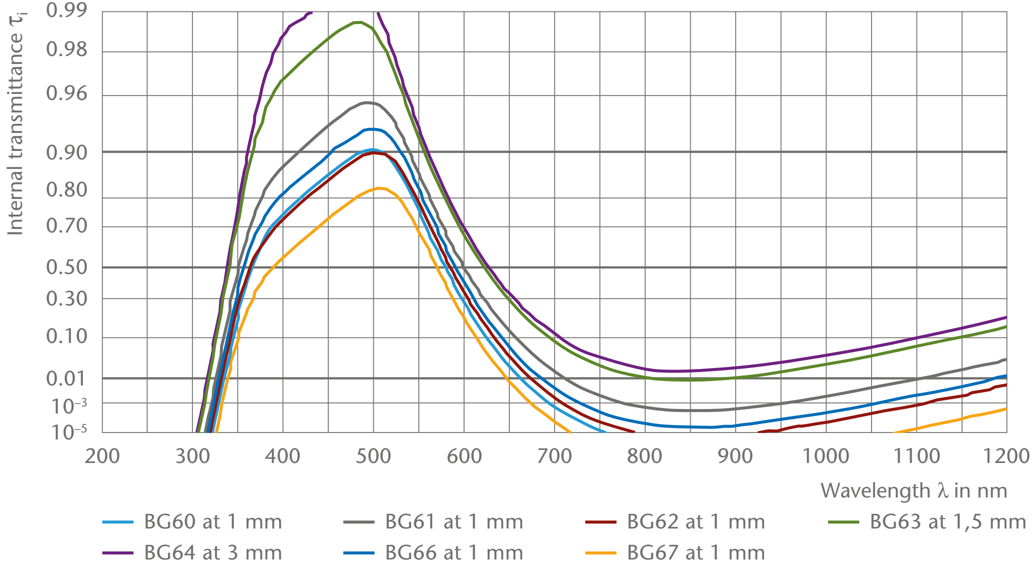
Bandpass filter BG glass types

Fig. 4.4



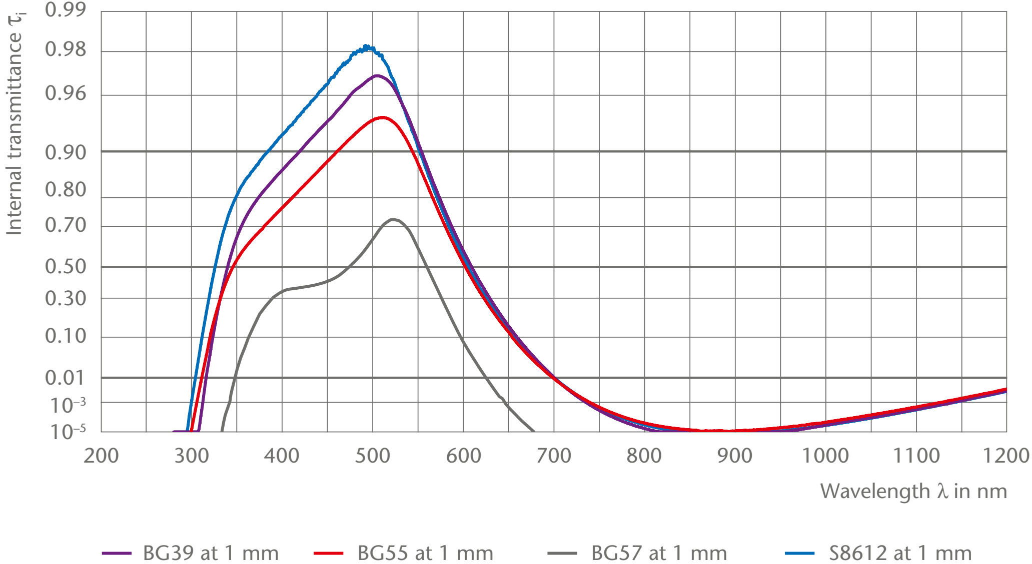
Bandpass filter BG glass types

Fig. 4.5



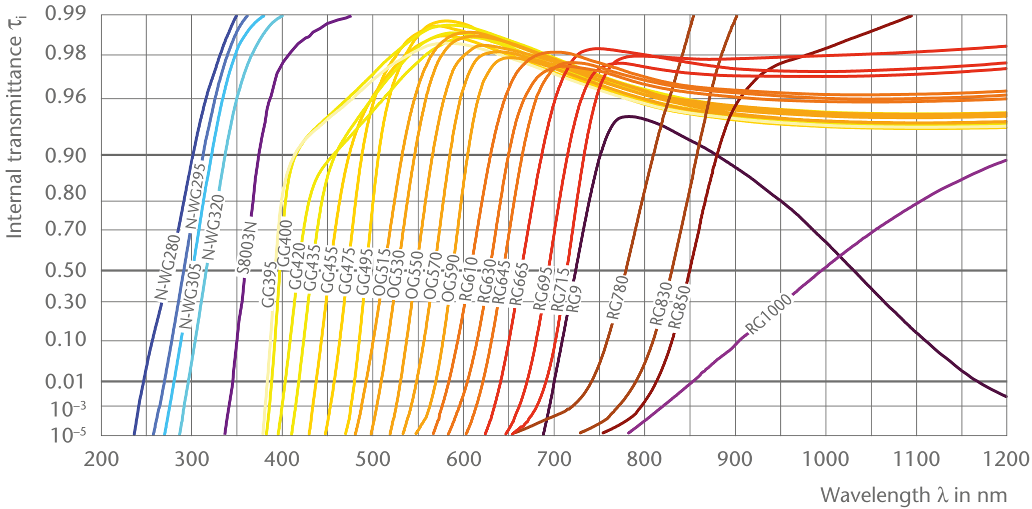
Bandpass filter S, BG glass types

Fig. 4.6



Longpass filter N-WG, GG, OG, RG glass types

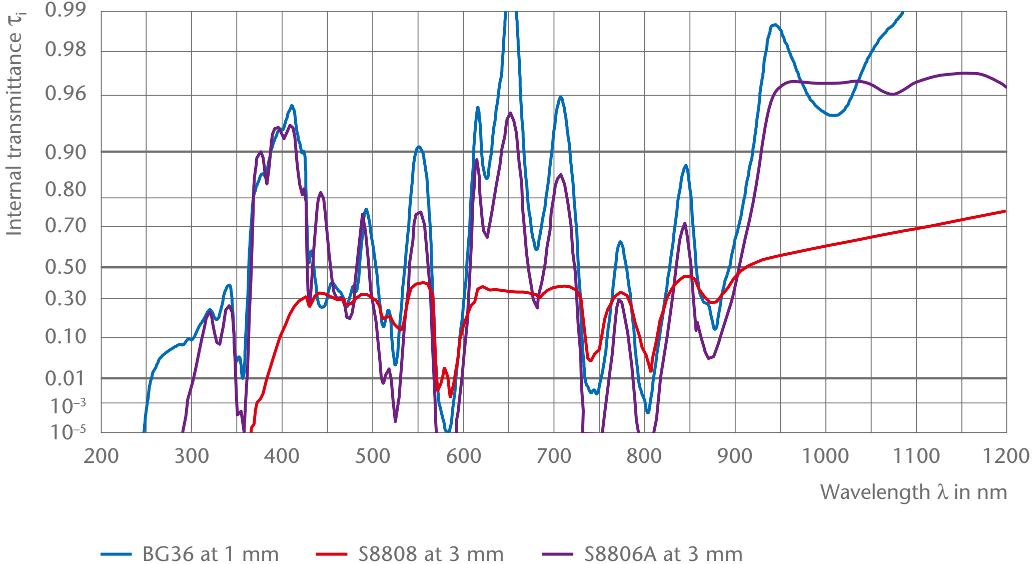
Fig. 4.7



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

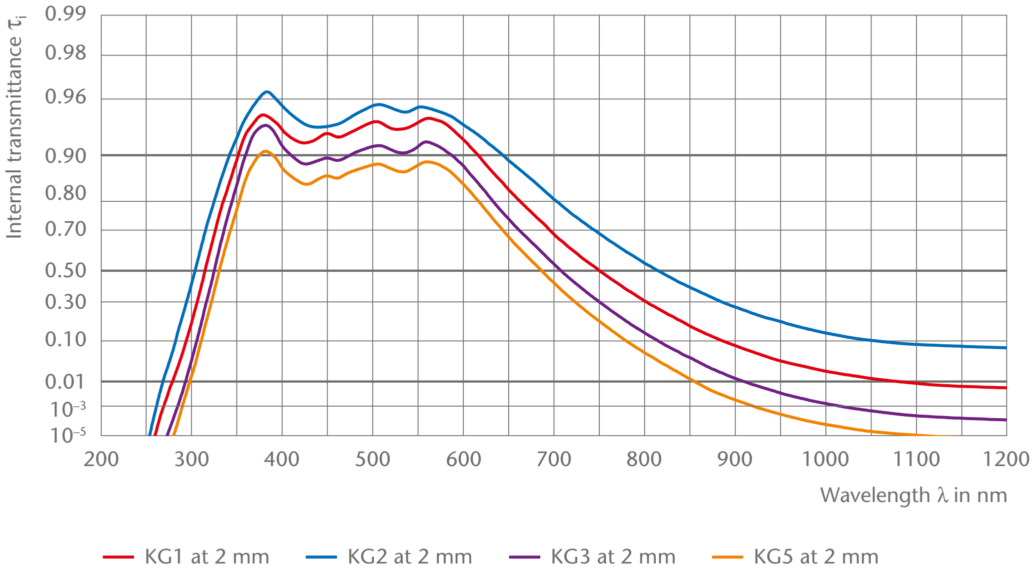
Multiband filter BG glass type

Fig. 4.8



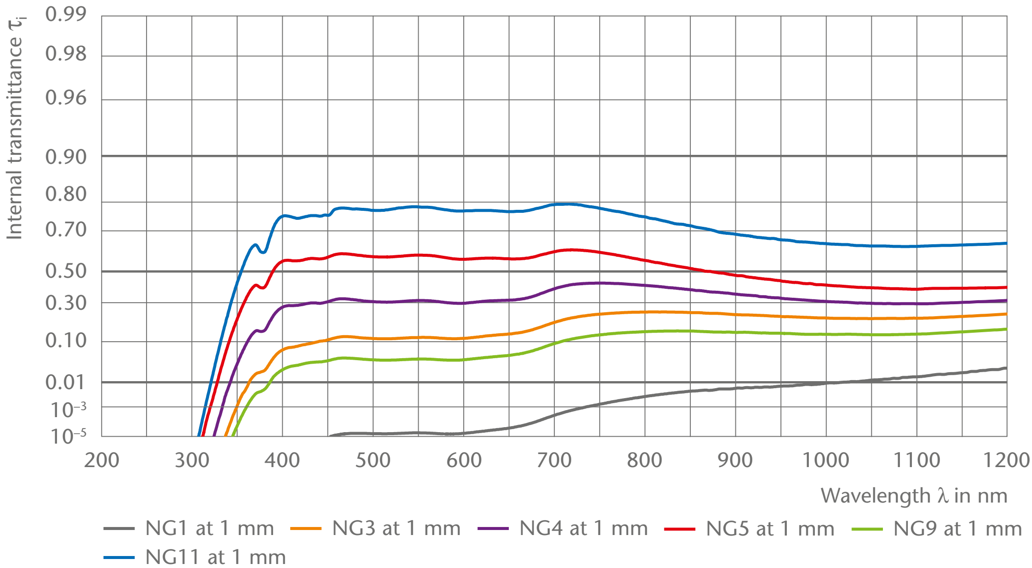
Shortpass filter KG glass types

Fig. 4.9



Neutral density filter NG glass types

Fig. 4.10

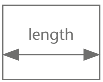
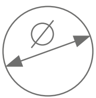


5 Tolerances for polished filters

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

5.1 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.

Rectangular shape	**Edge length [mm]**	**Minimum thickness [mm]**		**Chamfer [mm]**
		precision	**standard**	
	≤ 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	
Disc shape	**Diameter [mm]**	**Minimum thickness [mm]**		**Chamfer [mm]**
		precision	**standard**	
	≤ 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 special request. Min Ø 4 mm.			

5.2 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'

5.3 Optical quality

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

Imprint

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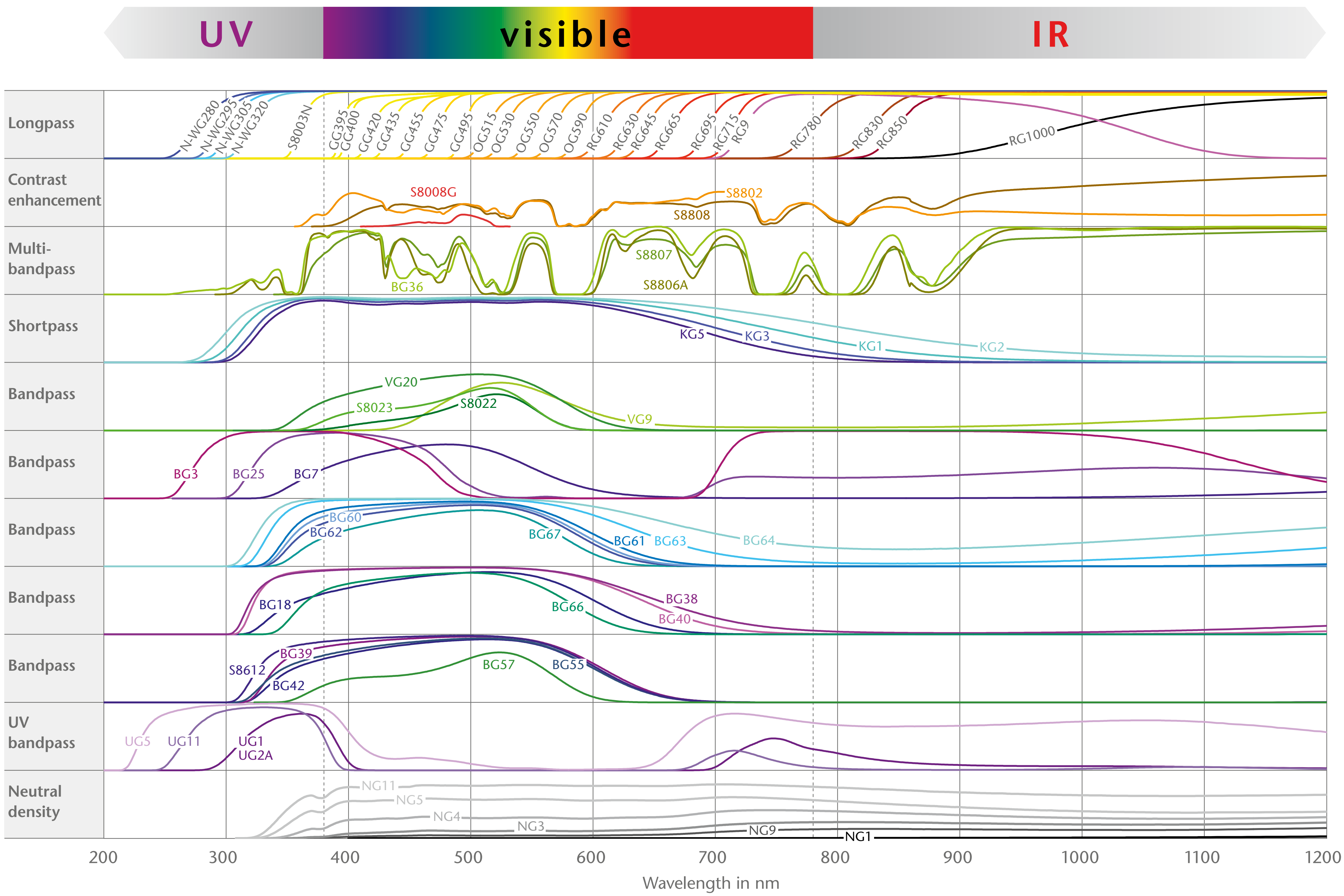
Optical filter glass – internal transmittance



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