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

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

SCHOTT: Your Partner for Excellence in Optics.
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1. Introduction

1.1 Foreword

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

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

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

- High transmittance
- High blocking
- Filter curves hardly depend on the light angle
- Superior quality, reliability and durability
- No polarization effects
- Experience with high demands on surface quality, extremely thin and small tolerances when manufacturing complex glass types
- In-house optical and protection coating capabilities
- Ability to accommodate special requirements via close collaboration and development efforts between our customers and our application engineering team
- All colored filter glass types can be used as substrates for thin film coating to manufacture interference filters. Thus, specific advantages (absorption properties of a colored filter glass and the reflection properties of interference coatings) can be combined to one optical filter.
SCHOTT’s optical filter glass portfolio is the product line of choice for system designers and optical engineers and is being constantly updated, reflecting the market needs. While advancing its capabilities, SCHOTT has continuously expanded its optical filter glass portfolio. Thus, now it contains special bandpass filters BG60, BG61 and BG62 as NIR-cut filter for imaging applications.

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

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

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

The release of this brochure replaces all previous publications.

January 2015
1.2  General information on listed data

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

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

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

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

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

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

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

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

In addition, all materials discussed in this brochure comply with the requirements of the European Regulation 2006/1907/EC (REACH: Registration, Evaluation and Authorization of Chemical Substances).
The optical filter glass portfolio of SCHOTT consists of the following filter types in the wavelength range above 200 nm:

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

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

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

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

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

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

2.1 Group names

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

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

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

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

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

**Neutral density filter**
- NG  Grey glass with uniform attenuation in the visible range

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

---

* NIR as defined in ISO 4007 is the wavelength range IR-A from 780 nm to 1.400 nm.
The various optical filter glass types can be divided into three classes based on their material composition:

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

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

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

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

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

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

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

3.1 Refractive index

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

3.2 Reflection loss at glass-air interface

At the glass-air interface a part of the incident air beam will be reflected. This reflection loss \( R \) is known as “Fresnel loss” and is a function of the refractive index of air \( n_{\text{air}} = 1 \) 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 constraint of incoherent radiation, perpendicular incidence, and considering multiple reflections, equation 1 applies.

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

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

![Fig. 3.1](image)

Definition of spectral transmittance (left) and internal spectral transmittance (right).
Definition of spectral transmittance:

\[ \tau(\lambda) = \frac{\Theta_{\lambda,\text{transmitted}}}{\Theta_{\lambda,\text{incident}}} \]

The spectral transmittance \( \tau(\lambda) \) in equation 2 is the ratio of the transmitted (energetic) spectral flux \( \Theta_{\lambda,\text{transmitted}} \) to the incident (energetic) spectral flux \( \Theta_{\lambda,\text{incident}} \). Hence \( \tau(\lambda) \) describes the transmittance of the absorbing glass filter considering the reflection losses at the front and rear sides of the filter.

The spectral transmittance can be measured easily. It is important to note that, in case of plano-parallel geometry of the substrate, the incident spectral flux and the transmitted spectral flux have the same wavelength \( \lambda \) and they are both traveling in the same direction. In the special case of luminescence (chapter 3.8) there is additional emerging flux present which has different wavelengths and which is diffuse. This additional energetic flux must be eliminated from the measurement of the transmittance \( \tau(\lambda) \).

Definition of internal spectral transmittance:

\[ \tau_i(\lambda) = \frac{\Theta_{\lambda,\text{leaving}}}{\Theta_{\lambda,\text{entering}}} \]

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

Using R:

\[ \tau = \frac{(1-R)^2 \tau_i}{1-\tau_i R^2} \quad \text{and} \quad \tau_i = -\frac{(1-R)^2}{2R^2} + \sqrt{\frac{(1-R)^4}{4R^4} + \frac{1}{R^2}} \]

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

\[ \tau(\lambda) = P(\lambda) \cdot \tau_i(\lambda) \]

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

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

\[ \tau_i d_1(\lambda) = \tau_i d_2(\lambda)^{d_1/d_2} \]
\( \tau_{i,d_1}(\lambda) \): Internal transmittance at the wavelength \( \lambda \) and with filter thickness \( d_1 \).

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

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

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

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

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

### 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

\[
D(\lambda) = \lg \frac{1}{\tau(\lambda)}
\]

#### 3.4.2 Spectral absorbance (extinction)

\[
A(\lambda) = \lg \frac{1}{\tau_i(\lambda)}
\]

#### 3.4.3 Spectral diabatie

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

**Note:** For optical filter glass the spectral diabatie is calculated using the internal transmittance \( \tau_i \). For interference filters, which have special reflectance properties, the spectral diabatie is derived using the spectral transmittance \( \tau \).

#### 3.4.4 Luminous transmittance

\[
\tau_{\nu,D65} = 100\% \quad \frac{\int_{\lambda=380\text{ nm}}^{780\text{ nm}} \tau(\lambda) \cdot S_{D65}(\lambda) \cdot V(\lambda) \, d\lambda}{\int_{\lambda=380\text{ nm}}^{780\text{ nm}} S_{D65}(\lambda) \cdot V(\lambda) \, d\lambda}
\]

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

The $\tau_i(\lambda)$ values for the appropriate reference thicknesses are presented graphically in the “Properties” brochure. The wavelength from 200 nm to 1200 nm is shown as the abscissa. The internal transmittance $\tau_i(\lambda)$ is shown as the ordinate in a special log-log-scale (see spectral diabatic). 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

3.6.1 Longpass 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.

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

The important properties applicable to optical filter glasses:

- $\lambda_c$: Edge wavelength or cutoff wavelength at which point the spectral internal transmittance has a value of 0.5.
- $\lambda_s$: The limit of the blocking range. Below this wavelength, the internal transmittance has a value below $\tau_{i,s}$ for a certain spectral region.
- $\lambda_p$: 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 $\tau_{i,p2} = 0.97$. 

![Fig. 3.2 Longpass filter](image-url)
3.6.2 Shortpass filters

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

![Shortpass filter diagram](image)

3.6.3 Bandpass filters

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

![Bandpass filter diagram](image)
Neutral density filters exhibit nearly constant spectral transmittance in the range of the visible light, for example from 400 nm to 800 nm, and are therefore only slightly wavelength dependent. Neutral density filters are therefore perfectly grey in color.

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

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

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

The more or less pronounced luminescence of the optical filter glasses is only interesting for practical purposes if these filters are to be used to measure the luminescence of materials. Here, the application of optical filter glasses as excitation filters, i.e. for spectral isolation of the exciting radiation, presents no problem in most cases.
Fig. 3.6
SCHOTT optical filter glass portfolio: The transmittance of all filters is depicted in 9 groups, where the ordinate is in linear scale.
3.9 Color

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

The following values are listed in the datasheets for our “colored” filter glasses, which exclude black, neutral density, and clear glasses: x, y, Y, \( \lambda_d \), and \( P_e \).

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

The tristimulus values listed in the datasheets are reference values only.
Chromaticity coordinates relevant to Night Vision Imaging Systems (NVIS) compatibility are described in terms of the UCS coordinates $u'$ and $v'$. These coordinates are directly related to the CIE$^1$ $x$ and $y$ coordinates by way of the following formula:

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

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 $Z$:

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

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:

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

where:

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

### 3.10 Brightness/photopic transmittance

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

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

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$^1$ Commission Internationale de l’Eclairage, Vienna, Austria. http://www.cie.co.at/
Optical filter glasses in different shapes and supply forms (coated, cemented, etc.).
4. Thermal and mechanical properties

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

4.1 Mechanical density $\rho \text{[g/cm}^3\text{]}$

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

4.2 Strength

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

4.3 Thermal toughening

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

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

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

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

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

4.4 Transformation temperature $T_g$ [°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 $T_g$ which is defined according to ISO 7884-8. As a rule of thumb, a maximum temperature $T_{\text{max}} = T_g - 200$ °C should not be exceeded during filter operation as the glass and filter properties may otherwise change permanently.

4.5 Thermal expansion $\alpha$ [$10^{-6}$/K]

The coefficient of thermal expansion (CTE or $\alpha$) 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] denotes the linear coefficient of thermal expansion in the range of $[-30 \degree C; +70 \degree C]$

$\alpha_{20/300}$[°C] denotes the linear coefficient of thermal expansion in the range of $[20 \degree C; 300 \degree C]$

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 $[20 \degree C; 200 \degree C]$ due to their low transformation temperature.
5. Chemical properties

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

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

5.1 Stain resistance

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

The stain resistance class is determined according to the following procedure:

The plane polished glass sample to be tested is pressed onto a test cuvette, which has a spherical depression of max. 0.25 mm depth containing a few drops of test solution I or II.

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

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

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

<table>
<thead>
<tr>
<th>Stain Resistance Classes FR</th>
<th>0</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Test solution</td>
<td>I</td>
<td>I</td>
<td>I</td>
<td>I</td>
<td>II</td>
<td>II</td>
</tr>
<tr>
<td>Time (h)</td>
<td>100</td>
<td>100</td>
<td>6</td>
<td>1</td>
<td>1</td>
<td>0.2</td>
</tr>
<tr>
<td>Color change</td>
<td>no</td>
<td>yes</td>
<td>yes</td>
<td>yes</td>
<td>yes</td>
<td>yes</td>
</tr>
</tbody>
</table>
5.2 Acid resistance

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

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

The time \( t \) required to dissolve a layer with a thickness of 0.1 \( \mu \)m serves as a measure of acid resistance. Two aggressive solutions are used in determining acid resistance. A strong acid (nitric acid, \( c = 0.5 \text{ mol/l}, \text{pH 0.3} \)) 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 \( \mu \)m at a pH value of 0.3 is less than 0.1 hour and at a pH value of 4.6 is greater than 10 hours.

<table>
<thead>
<tr>
<th>Acid Resistance Classes SR</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>51</th>
<th>52</th>
<th>53</th>
</tr>
</thead>
<tbody>
<tr>
<td>pH value</td>
<td>0.3</td>
<td>0.3</td>
<td>0.3</td>
<td>0.3</td>
<td>0.3</td>
<td>4.6</td>
<td>4.6</td>
<td>4.6</td>
</tr>
<tr>
<td>Time (h)</td>
<td>&gt;100</td>
<td>10–100</td>
<td>1–10</td>
<td>0.1–1</td>
<td>&lt;0.1</td>
<td>&gt;10</td>
<td>1–10</td>
<td>0.1–1</td>
</tr>
</tbody>
</table>

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 \( \mu \)m thick layer of glass in an alkaline solution (sodium hydroxide, \( c = 0.01 \text{ mol/l}, \text{pH 12} \)) at a temperature of 50 °C.
The layer thickness is calculated based on the weight loss per surface area and the density of the glass.

<table>
<thead>
<tr>
<th>Alkali Resistance Classes AR</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time (h)</td>
<td>&gt;4</td>
<td>1–4</td>
<td>0.25–1</td>
<td>&lt;0.25</td>
</tr>
</tbody>
</table>

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)

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

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

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

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

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

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

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

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

6.1 Bubbles and inclusions

SCHOTT optical filter glasses are characterized by their particularly small number of bubbles. However, it is not always possible to avoid bubbles in the glass. The description of the content of bubbles and inclusions varies for unpolished glass and polished optical filter components. The reason is that bubble classes for unpolished glasses are defined for a rather large volume of 100 cm³, while polished optical filter components are often much smaller. Therefore, it is not at all unusual to produce bubble-free components from a block of filter glass with bubble class 3.

The bubble content of an optical filter glass is characterized by stating the total 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 of the same cross-sectional area. Only bubbles and inclusions that are larger than 0.03 mm in diameter are covered in the assessment. The bubble classes are shown in table 6.1:

<table>
<thead>
<tr>
<th>Bubble class of matte plates</th>
<th>Total cross-section of all bubbles/inclusion ≥ 0.03 mm³ in mm² per 100 cm³ of glass volume</th>
</tr>
</thead>
<tbody>
<tr>
<td>B0</td>
<td>≤ 0.03</td>
</tr>
<tr>
<td>B1</td>
<td>&gt; 0.03 ≤ 0.10</td>
</tr>
<tr>
<td>B2</td>
<td>&gt; 0.10 ≤ 0.25</td>
</tr>
<tr>
<td>B3</td>
<td>&gt; 0.25 ≤ 0.50</td>
</tr>
</tbody>
</table>

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

The internal quality of optical filter glass components must be specified in accordance with the standard ISO 10110 Part 3. Should no specifications be made by the customer upon ordering, the permissible amount of bubbles and inclusions is 1/5 × 0.4 for all sizes of polished filters. (This complies with the regulations of ISO 10110 part 11 at a standard size of the filter of over 30 mm and up to 100 mm.) This specification is valid only if the transmittance of the filter is high enough.

For filters that are too dark for inspection, only surface defects can be inspected, and the minimum requirements of ISO 10110 part 11 apply for the surface imperfections. Tighter specifications are possible on request.
SCHOTT offers high-performance, custom-designed, unpolished, polished, and coated optical filters to meet your application demands.

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

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

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

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

6.2 Striae

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

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

6.3 Homogeneity of refractive index

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

7. Further processing of optical filter glass

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

7.1 Polished optical filters

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

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

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

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.us.schott.com/advanced_optics/optical-filter-glass or contact a sales representative.

BG filters are ideally suited for use as NIR cut filters.
This chapter gives a short overview of some applications which utilize optical filter glasses.

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

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

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

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

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

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

Neutral density glasses with the designation NG offer, as their name implies, rather constant transmission over a broad spectral range, especially in the visible range. The degree of desired filtering can be regulated by using different NG filter types and thicknesses in a specific type of filter. Their use is indicated when the user requires defined attenuation of the intensity of radiation sources over a broad spectral range.
The various optical filter glasses from the **BG group** are used to **correct the sensitivity of silicon receivers**, with their maximum sensitivity in the range between approx. 800 nm and 900 nm, depending on the type of silicone sensors. The increase in detection sensitivity from the blue to the near infrared in detection results in an over evaluation of the longwave (red) area. By selecting the appropriate BG glasses, this can be compensated to a certain extent.

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

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

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