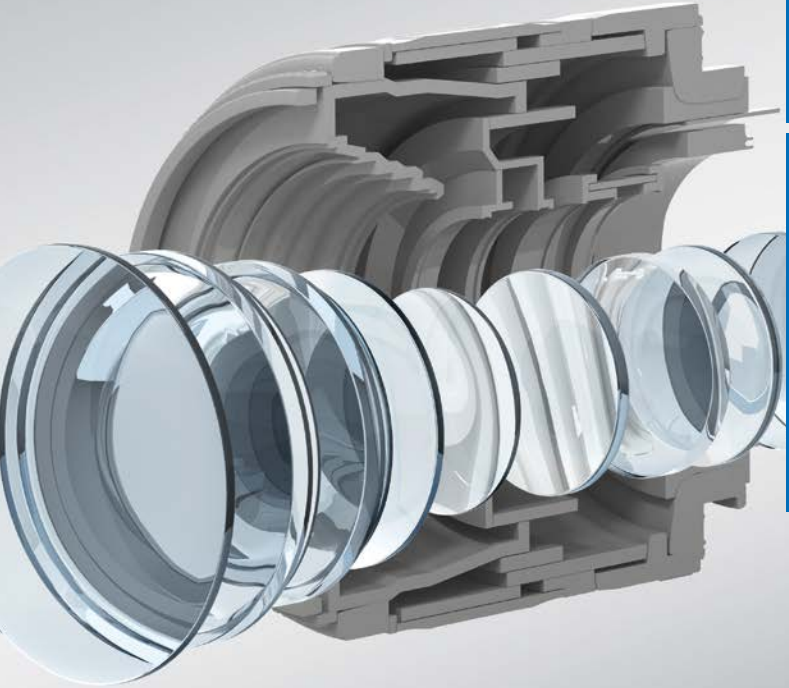
SCHOTT
glass made of ideas



Optical Glass 2016

Optical Glass 2016

Description of Properties

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1 Optical Properties

Foreword

SCHOTT Advanced Optics –
Your Partner for Excellence in Optics.

SCHOTT is an international technology group that is active in the areas of specialty glasses and glass-ceramics. The company has more than 130 years of outstanding development, materials and technology expertise and we offer a broad portfolio of high-quality products and intelligent solutions, thus contributing to our customers' success.

Today, SCHOTT´s Advanced Optics unit offers optical materials, components and filters and has been a trailblazer for various applications. With a product portfolio of over 120 optical glasses, special materials (e.g. active laser glass, IR-Materials, sapphire), ultra-thin glass, high-precision optical components, wafers, and optical filter glasses, Advanced Optics develops customized solutions all over the world for applications in optics, lithography, astronomy, opto-electronics, life sciences, research, and more.

Advanced Optics masters the entire value chain: from customer-specific glass development and its production all the way to high-precision optical product finishing, processing and measurement.

Otto Schott (1851–1935)

For more information on Advanced Optics, please visit our website: *http://www.schott.com/advanced_optics/english/index.html*.

NEW

What's new?

SCHOTT Advanced Optics still continues to come up with new product innovations. This is what enables us to steadily expand our portfolio to include new high-quality glasses for use in optical and industrial applications and meet the changing demands of the market and our customers' needs.

Thanks to the close cooperation between our skilled research and development teams, we are able to continue to expand our products and their range of applications. This, in turn, enables us to offer our customers all over the world an even broader range of products that effectively meet their needs.

Here are just a few examples of innovations from SCHOTT Advanced Optics:

- Step 0.5 now available for pressings (See Chapter 1.2)
- The test report contains more refractive index information (See Chapter 1.3)
- Stitching of large aperture homogeneity measurement (See Chapter 1.4)
- SCHOTT XLD glasses (eXtreme Low Dispersion) (See Chapter 13)

Improving the quality and processability of our products on a regular basis is extremely important to us at SCHOTT. On the way to achieving this, however, a few changes have been made to the properties of our glasses. You will find these products and the respective changes in our “Change Index – Part II Optical Glass – Properties” catalog in Chapter 12.

We have also worked very hard to ensure that all of the glass products covered in this catalog meet the requirements of the RoHS II Directive and the REACH Regulation. Ensuring the safety of both people and the environment has always been an important objective for SCHOTT. For this reason, we are particularly pleased that our efforts to limit the use of potentially harmful substances and establish best practices for the safe manufacturing and handling of these products have been so successful.

If you require any information that isn't included in this catalog, please contact a local member of our global sales force. We would be happy to work with you and develop a customized solution for meeting your specific requirements.

SCHOTT will continue to expand its product portfolio in the future and reserves the right to change the information contained in this catalog without giving prior notice. The latest edition was assembled with the greatest care; nevertheless SCHOTT accepts no liability in the unlikely event that it contains any incorrect information or printing errors. The current catalog 0116 replaces all previous editions. The legally binding version of this catalog is available on our website:
www.schott.com/advanced_optics/downloads-e

Advanced Optics
SCHOTT AG
Mainz
January 2016

LRQA
Business Assurance

CERTIFICATE OF APPROVAL

This is to certify that the Quality and Environmental Management System of:

SCHOTT AG
Business Segment Advanced Optics
Hattenbergstr. 10, 55122 Mainz
Germany

has been approved by Lloyd's Register Quality Assurance to the following Quality and Environmental Management System Standards:

DIN EN ISO 9001:2008, DIN EN ISO 14001:2009

The Quality and Environmental Management System is applicable to:

Development, manufacturing and coating of optical glasses, glass ceramics and speciality glass as well as components.

Approval Certificate No: KLN 0300080
KLN 4001214
KLN 4001246
KLN 4001264
UQA 4001330

Original Approval ISO 9001: see single certificates
Original Approval ISO 14001: see single certificates
Current Certificate: see single certificates
Certificate Expiry: see single certificates

Issued by: Lloyd's Register Quality Assurance GmbH
For and on behalf of: Lloyd's Register Quality Assurance Limited

GOLD AWARD

LRQA: Certificate for SCHOTT, Advanced Optics, Mainz, Gold Award for being certified for more than 10 years

Further Product Information

One of SCHOTT's main objectives is to provide professional support in addition to supplying current products. Extensive technical mentoring, detailed product information and application support before and after a product is purchased and joint developments of customized solutions highlight our uniqueness. We offer detailed data sheets, databases for use with optical design programs and survey diagrams for all materials listed in this catalog. Electronic versions of technical information or so-called TIEs are also available.

The stamp shown here is placed within this catalog and indicates the availability of relevant Technical Information (TIE). An overview is shown on page 74 of this catalog. Detailed technical information can be found online at: *http://www.schott.com/advanced_optics/english/knowledge-center/technical-articles-and-tools/tie.html*

TIE available →

Optical Glass Catalog

In this **catalog**, you will find an overview of our optical glasses and materials that cover the needs of a wide range of applications from consumer products to optical systems at the cutting edge of research.

We address the following categories:
- "N"-glasses as an environmentally friendly alternative to conventional lead and arsenic-containing glass types
- Classic glass types with lead oxide as an essential component for outstanding optical properties
- Optical glasses with enhanced transmission values in the visible spectral range, especially in the blue-violet range: HT & HTultra glasses
- High homogeneity glasses available from stock
- "P"-glasses for the precision molding process (Low T_g glasses)
- i-line glasses for microlithography
- Radiation resistant glass types
- XLD glasses (eXtreme Low Dispersion)

While addressing these different categories, SCHOTT distinguishes between Preferred Glass Types, usually kept in stock for immediate delivery, and **Inquiry Glass Types**, which can be ordered, although SCHOTT cannot guarantee that they will be in stock. Details are listed in the Part II Optical Glass – Properties section of the catalog.

Relevant definitions for the glasses listed in this catalog:

TIE-42 Radiation resistant optical glasses →

The cerium-stabilized **radiation resistant glass** types are used to maintain transmittance in an ionizing radiation environment and also rank among our inquiry glasses.

The optical data for the glasses listed in this catalog are meant for use in optical applications and therefore refer to air.

Supply Forms

SCHOTT offers **different supply forms** of the glasses available.
Detailed information is included in chapter 7.

Quality Management

SCHOTT operates a globally centralized Management System. It integrates the requirements of ISO 9001 on Quality Management, ISO 14001 on Environmental Management, ISO 50001 on Energy Management and on the Policy and Standards of SCHOTT on Environmental, Health and Safety System in accordance with OHSAS 18001. This results in compliance with environmental regulations such as RoHS II and REACH (refer to chapter 3.6) and assures a high quality level (refer to chapter 6.1). In addition, SCHOTT recently implemented large parts of ISO 12123 “Optics and Photonics – Specification of Raw Optical Glass” which has been taken into account in the updated version of this catalog. References are provided in the descriptions.

1 Optical Properties

1.1 Refractive Index, Abbe Number, Dispersions, Glass Designations

TIE-29 Refractive index and dispersion →

The most common identifying features for characterizing an optical glass are the refractive index n_d in the middle range of the visible spectrum and the Abbe number $\nu_d = (n_d - 1)/(n_F - n_C)$ as a measure for dispersion. The difference $n_F - n_C$ is referred to as the principal dispersion.

Optical glass can also be designated by a numerical code, often called the glass code. Here, SCHOTT uses a nine-digit code. The first six digits correspond to the common international glass code. They indicate the optical position of the individual glass. The first three digits reflect the refractive index n_d, the second three digits the Abbe number ν_d. The additional three digits show the density of the glass.

Table 1.1: Examples of glass codes

Glass type	n_d	ν_d	Density	Glass code
N-SF6	1.80518	25.36	3.37	805254.337
SF6	1.80518	25.43	5.18	805254.518

When specifying optical systems, the values based on the e-line n_e and $\nu_e = (n_e - 1)/(n_{F'} - n_{C'})$ are other commonly established quantities.

Preferred optical glasses are grouped as families in the n_d/ν_d or n_e/ν_e diagram. The glass families are listed in the Part II Optical Glass – Properties section in order of decreasing Abbe numbers.

1.2 Tolerances for Refractive Index and Abbe Number

The tolerances for the refractive index and Abbe number are listed in Table 1.2. The standard delivery quality for fine annealed glass is Step 3 for n_d and ν_d. We supply material in tighter steps upon request. Selected glass types can be delivered in Step 0.5 for refractive index and Abbe number. The available glass types are marked in the Part II Optical Glass – Properties section of the glass catalog. Step 0.5 is also available for fine annealed optical glass as well as pressings.

Table 1.2: Tolerances for refractive index and Abbe number (according to ISO 12123)

	n_d	ν_d
Step 0.5*	±0.0001	±0.1 %
Step 1	±0.0002	±0.2 %
Step 2	±0.0003	±0.3 %
Step 3	±0.0005	±0.5 %

* only for selected glass types

All deliveries of fine annealed optical glass are made in lots of single batches (see Fig. 1.1).

The batch may be a single block or several strips. The delivery lots are identified by a delivery lot number.

The delivery lots are formed based on the specified maximum allowed refractive index and Abbe number deviation of single batches from the nominal values in the data sheets (tolerances according Table 1.2) and the refractive index variation from batch to batch as specified in Table 1.3.

As the batches may have different fine annealing histories, such delivery lots are not suitable for repressing. All parts of a delivery lot of fine annealed optical glass, cut blanks or pressings meet the normal quality of refractive index variation as listed in the following Table 1.3. If requested, parts can also be supplied in lots with tighter refractive index variations than indicated in Table 1.3.

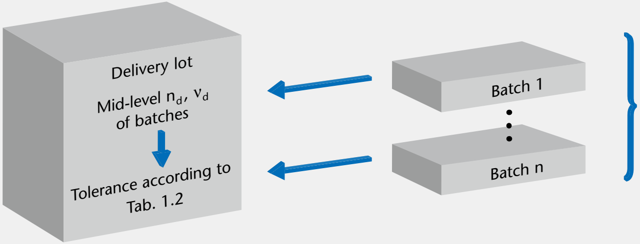
Table 1.3: Tolerance of refractive index variation within a lot of fine annealed glass (according to ISO 12123) and within a lot of pressings

Fine annealed glass, cut blanks		Pressings	
Designation	**Refractive index variation**	**Designation**	**Refractive index variation**
SN	$\pm 10 \cdot 10^{-5}$	LN	$\pm 20 \cdot 10^{-5}$
S0	$\pm 5 \cdot 10^{-5}$	LH1	$\pm 10 \cdot 10^{-5}$
S1	$\pm 2 \cdot 10^{-5}$	LH2	$\pm 5 \cdot 10^{-5}$

Fig. 1.1: Delivery lot compilation of glass for hot processing and fine annealed glass

Delivery lot:
Lot of single batches with
identical properties

Batch:
A single block of glass or several strips produced
in a given period of time with individual n_d and ν_d.



Max. refractive index variation
from batch to batch:
SN, S0 or S1 according to Tab. 1.3

SCHOTT is responsible for the combination of batches within a delivery lot.

1.3 Test Reports for Refractive Indices and Dispersions

1.3.1 Standard test reports

We provide standard test reports according to ISO 10474 for all deliveries of fine annealed optical glass. The information they contain is based on sampling tests and refers to the mid-level position of the optical values of a delivery lot. The value of the individual part may deviate from the reported mid-level value in terms of the tolerance of the refractive index variation.
Measurements are carried out with an accuracy of $\pm 3 \cdot 10^{-5}$ for refractive index and $\pm 2 \cdot 10^{-5}$ for dispersion. Numerical data is listed down to five decimal places.

Table 1.4: Refractive index and dispersion information in standard test reports

Optical position	n_d, ν_d, n_e, ν_e
Refractive index	n_g, $n_{F'}$, n_F, n_e, n_d, $n_{632.8}$, $n_{C'}$, n_C, n_r, n_s, n_t
Dispersions	$n_F - n_C$, $n_d - n_C$, $n_F - n_d$, $n_F - n_e$, $n_g - n_F$, $n_{F'} - n_{C'}$, $n_{F'} - n_e$

Test certificates that are even more accurate can be provided for individual glass parts upon request ($\pm 2 \cdot 10^{-5}$ for refractive index and $\pm 1 \cdot 10^{-5}$ for dispersion). These certificates also list the constants of the Sellmeier dispersion formula for the applicable spectral range evaluated from a complete measurement series.

1.3.2 Precision test certificates UV-VIS-IR

Precision test certificates are issued upon request and always refer to individual glass parts.

Within the visible spectral range, these certificates contain the same quantities as the test reports for standard accuracy, however the dispersion data is reported down to six decimal places. Upon request, refractive index data can be provided for an expanded spectral range of 185 nm to 2325 nm and the constants of the Sellmeier dispersion formula can be listed for the applicable spectral range.

Measurements are carried out using a prism spectrometer. The accuracy is $\pm 1 \cdot 10^{-5}$ for refractive index and $\pm 3 \cdot 10^{-6}$ for dispersion. Accuracy of up to $\pm 4 \cdot 10^{-6}$ for the refractive index and $\pm 2 \cdot 10^{-6}$ for the dispersion measurement, independent of the glass type and measurement wavelength, can be provided upon request.

The measurement temperature is 22 °C. The measurement temperature can be changed to a constant value between 18 °C and 28 °C upon request. The standard measurement atmosphere is air at a pressure of about 1013.3 hPa. The actual measurement temperature and pressure are indicated on the individual test certificates. Measurements in a nitrogen atmosphere are possible upon special request.

1.4 Refractive Index Homogeneity

TIE-26 Homogeneity of optical glass →

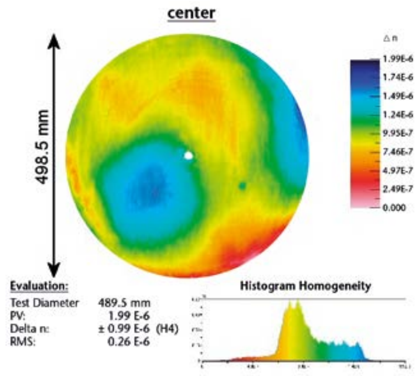
The refractive index homogeneity is a measure for designating deviations in the refractive index in individual pieces of glass. Pieces of glass with a high homogeneity of refractive index can be obtained by undertaking special efforts in the area of melting and fine annealing. The refractive index homogeneity that can be achieved depends on the type of glass, the volume and the shape of the individual glass piece.

The required optical homogeneity should be specified with respect to the application and the final dimensions of the optical component. This generally corresponds with the maximum refractive index variation within the desired testing aperture (e.g. 95 % of the physical dimension). The refractive index variation is calculated from the interferometrically measured wavefront deformation. In many cases certain aberration terms with negligible impact on the application can be subtracted. For example, focal aberrations (expressed by the focal term) can often be corrected by adapting the geometry of the final part. This should be specified in advance. The gradient of the homogeneity distribution can be evaluated in terms of refractive index variation per cm aperture upon request. This too should be specified in advance. Increased requirements for refractive index homogeneity comprise five classes in accordance with the standard ISO 10110 Part 4 (see Table 1.5). The maximum deviation of refractive index is expressed in peak to valley values in accordance with ISO 12123. Depending on the volume of the optical element and other factors, such as the type of glass and the size of the blank used, the measurement of the wavefront deformation is carried out on a single piece. Glass parts of up to 500 mm in diameter can be tested with the existing Fizeau-interferometer. Glass parts with diameters up to 1500 mm are measured in sub-apertures of up to 500 mm in diameter. Subsequently, the individual measurements are combined using a stitching software. Individual interferograms can be made available for each piece of glass.

Table 1.5: Homogeneity of optical glass according to ISO 10110 and ISO 12123

Homogeneity class	Maximum variation of refractive index	Applicability, deliverability
H1	$40 \cdot 10^{-6}$	For individual cut blanks
H2	$10 \cdot 10^{-6}$	For individual cut blanks
H3	$4 \cdot 10^{-6}$	For individual cut blanks, not in all dimensions
H4	$2 \cdot 10^{-6}$	For individual cut blanks, not in all dimensions, not for all glass types
H5	$1 \cdot 10^{-6}$	For individual cut blanks, not in all dimensions, not for all glass types

Fig. 1.2: H4 quality of a 1000 mm diameter SCHOTT N-BK7® blank measured with a central aperture of 500 mm



Evaluation:	
Test Diameter	489.5 mm
PV:	1.99 E-6
Delta n:	± 0.99 E-6 (H4)
RMS:	0.26 E-6

1.4.1 High Homogeneity Glass available from stock

SCHOTT offers a selection of optical glasses as fine annealed cut blanks in high homogeneities from stock.

Table 1.6. provides an overview of available glass types, dimensions, and homogeneity levels. The homogeneity specified is always achieved for at least 90 % of the diameter. For smaller diameters, higher homogeneities are also available on request.

Table 1.6: Stock of high homogeneity glasses and their available maximum dimensions and respective homogeneity grades

Glass Type*	Supply form*	Maximum available dimensions*	Homogeneity level
F2	discs	Ø 290 mm, thickness: 100 mm	H4
LF5	discs	Ø 220 mm, thickness: 45 mm	H4
LLF1	discs	Ø 220 mm, thickness: 45 mm	H4
SCHOTT N-BK7®	blocks	400 mm x 400 mm x 70 mm	H4
	blocks	250 mm x 250 mm x 100 mm	H4
N-FK5	discs	Ø 240 mm, thickness: 50 mm	H4
N-FK51A	discs	Ø 200 mm, thickness: 40 mm	H4
N-KZFS11	discs	Ø 170 mm, thickness: 40 mm	H4
N-LAK22	discs	Ø 200 mm, thickness: 50 mm	H4
SF5	blocks	150 mm x 150 mm x 60 mm	H4

*As in the past, other types of glass, supply forms and dimensions are available upon request (the dimensions depend on the glass type).

TIE-35 Transmittance of optical glass →

1.5 Internal Transmittance, Color Code

According to general dispersion theory, internal transmittance, i.e. the light transmittance excluding reflection losses, is closely related to the optical position of the glass type. Using the purest raw materials and sophisticated melting technology, it is possible to approach the dispersion limits for internal transmittance in the short wave spectral range.

SCHOTT seeks to achieve the best possible internal transmittance within economically reasonable limits.

The internal transmittance and color code listed in the Part II Optical Glass – Properties section represent median values from several melts of one glass type. Minimum values for internal transmittance can also be maintained for all glass types upon special request. Prior clarification of the delivery situation is necessary. The internal transmittance at 400 nm for a sample thickness of 10 mm is listed in the Part II Optical Glass – Properties section.

Some glasses are available with improved transmittance in the visible spectrum, especially in the blue-violet range. These products are marked with the suffix HT (High Transmittance) or HTultra (ultra High Transmittance) and will be shown separately in Part II Optical Glass – Properties section (like N-SF6HT or SF57HTultra). For HT and HTultra grade, the internal transmittance in the visible spectrum includes guaranteed minimum values.

The limit of the transmittance ranges of optical glasses towards the UV area is of particular interest in high index glasses because it moves closer to the visible spectral range with increases in the refractive index. A simple description of the position and slope of the UV absorption curve is shown by the color code.

The color code lists the wavelengths λ_{80} and λ_5 at which the transmittance (including reflection losses) is 0.80 and 0.05 at a thickness of 10 mm. The values are rounded off to 10 nm and denoted by eliminating the first digit. For example, color code 33/30 means $\lambda_{80} = 330$ nm and $\lambda_5 = 300$ nm.

For high index glass types with $n_d > 1.83$, the data of the color codes (marked by *) refers to the transmittance values 0.70 and 0.05 (λ_{70} and λ_5) because of the high reflection loss of this glass. The tolerance of the color code is ±10 nm.

1.5.1 I-Line glasses

i-Line glasses are optical glass types, which offer both high UV-transmittance at 365 nm and high refractive index homogeneity. These glass types, such as FK5HTi, LF5HTi, LLF1HTi and N-BK7HTi, are available in customized shapes and as final components.

i-Line glasses offer:
- High UV-transmittance at 365 nm
- High refractive index homogeneity (see Table 1.7)
- Excellent internal quality
- Negligible stress birefringence due to a well-defined annealing process
- Maximum refractive index variation per lot of less than $\pm 5 \cdot 10^{-6}$

Table 1.7: Refractive index homogeneity of i-line glasses relative to their dimensions

Dimension	**Maximum variation of refractive index**
Ø 150 mm	$0.5 \cdot 10^{-6}$
Ø 200 mm	$1.0 \cdot 10^{-6}$ (H5)
Ø 250 mm	$2.0 \cdot 10^{-6}$ (H4)

1.6 Measurement Capabilities for Optical Properties

Table 1.8 provides an overview of the measurement accuracy for the measurement procedures used to characterize optical properties in the quality assurance of optical glass.

Property		Accuracy		Method	Spectral range	Sample	
						Shape	Format
		refr. index	dispersion				
Refractive index	standard	$\pm 3 \cdot 10^{-5}$	$\pm 2 \cdot 10^{-5}$	V-block refractometer	g, F´, F, e, d, C´, C (ν_d, ν_e)	cube	$20 \cdot 20 \cdot 5$ mm^3
	increased	$\pm 2 \cdot 10^{-5}$	$\pm 1 \cdot 10^{-5}$		i, h, g, F´, F, e, d, C´, C, r, t (ν_d, ν_e)	cube	
	precision	$\pm 0.4 \cdot 10^{-5}$	$\pm 0.2 \cdot 10^{-5}$	Prism spectrometer	185–2325 nm	prism	side: 30 mm height: 22 mm
Internal transmittance		±0.5 % T ±0.3 % T		Spectro photometer	250–2500 nm 400–700 nm	cube	$30 \cdot 30 \cdot$ thickness in mm^3
Refractive index homogeneity		~10 nm wavefront pv		Fizeau-Interferometer	633 nm	rectangular circular	up to ~1500 mm diameter
Temperature coefficients of refraction		$\pm 5 \cdot 10^{-7} \cdot K^{-1}$		Prism spectrometer	i, h, g, F´, e, d, C´, t, 1060 –100 °C bis +140 °C	prism single side coated	side: 30 mm height: 22 mm
Precision measurement of stress birefringence		1 nm absolute (1 mm spatial resolution)		Imaging polarimeter	587 nm	arbitrary shape	up to 300 mm diameter

2 Internal Quality

2.1 Striae

TIE-25 Striae in optical glass →

Short range deviations of the refractive index in glass are called striae. They resemble layers of typical widths between tenths of a mm to the mm range.

The standard ISO 10110 Part 4 contains a classification with reference to striae. Since it refers to finished optical components, it is only applicable to optical glass in its original form of supply to a limited extent. It assigns the striae to classes 1–4 based on their area in terms of the optically effective total surface of the component. Thus, it only considers striae that deform a plane wave front by more than 30 nm.

The fifth class specifies glass that is extremely free of striae. It also includes striae below 30 nm wave front distortion and advises the user to make arrangements with the glass manufacturer.

The production formats of all optical glasses by SCHOTT meet the requirements of classes 1–4 of ISO 10110 Part 4. The tested glass thickness is usually much thicker than that of the finished optical components. Therefore, the effective striae quality in the optical system is much better.

Striae in optical glasses are detected by means of the shadowgraph method using comparison standards with known wavefront deviations. The tolerance limits in accordance with ISO 12123 are shown in Table 2.1.

Table 2.1: Tolerance limits for striae (according to ISO 12123)

Striae class	Striae wavefront deviation tolerance limit per 50 mm path length [nm]	Generally applicable for
Standard	< 30	raw glass
VS1-3	not visible with shadow method	cut blanks

Quality step VS specifies optical glass with increased striae selection. For optical glass in this quality category, no striae have been detected by the sensitive shadow method. For prism applications, SCHOTT offers quality step VS for 2 or 3 test directions perpendicular to one another.

2.2 Bubbles and Inclusions

TIE-28 Bubbles and inclusions in optical glass →

Optical glass is remarkably free of bubbles. However, due to the glass composition and the need for an economical manufacturing process, bubbles cannot be completely avoided in glass.

The bubble content is expressed by the total cross section in mm^2 in a glass volume of 100 cm^3, calculated from the sum of the detected cross section of bubbles. Inclusions in glass, such as stones or crystals, are treated as bubbles that have the same cross section. The evaluation considers all bubbles and inclusions ≥ 0.03 mm.

The maximum allowable total cross sections and maximum allowable quantity of bubbles and inclusions are listed in Table 2.2. In the increased quality steps VB (increased bubble selection) and EVB (extra increased bubble selection), the glasses can only be supplied as fabricated pieces of glass.

In accordance with ISO 10110 Part 3, bubbles may be distributed. Instead of a bubble with a given dimension, a larger quantity of bubbles of smaller dimensions is allowed.

Table 2.2: Limit values for bubbles and inclusions in optical glasses

Quality of bubbles	Standard	VB	EVB
Total cross section in mm^2 per 100 cm^3	0.03	0.02	0.006
Maximum allowed quantity per 100 cm^3	10	4	2

Special applications, such as high energy lasers, beam splitter prisms or streak imaging cameras and high pitch gratings, only tolerate glasses that have a small number of tiny bubbles/inclusions. We can offer glass that meets these requirements upon request.

2.3 Stress Birefringence

TIE-27 Stress in optical glass

The size and distribution of permanent inherent stress in glass depends on the annealing conditions, the glass type, and the dimensions. The extent to which stress causes birefringence depends on the glass type.

Stress birefringence is measured as a path difference using the de Sénarmont and Friedel method and is listed in nm/cm based on the test thickness. Its accuracy is 3 – 5 nm for simple geometric test sample forms. Measurements are carried out on round discs at a distance of 5 % of the diameter from the edge. For rectangular plates, the measurement is taken at the center of the longer side at a distance of 5 % of the plate width. A detailed description of this method can be found in ISO Standard 11455.

The manual de Sénarmont and Friedel method is insufficient for measurements of low stress birefringence and low thickness. In these cases, we have systems for measuring with an accuracy of 1 nm or less.

With our annealing methods, we are able to achieve both high optical homogeneity and very low stress birefringence. The pieces of glass that are delivered generally have symmetrical stress distribution. The glass surface is usually under compression. Stress birefringence can be reduced significantly by cutting block or strip glass. If the optical elements are much smaller than the raw glass format they are made of, then the remaining stress birefringence will be even lower than the limiting values shown in Table 2.3.

The limit values for stress birefringence in parts larger than 600 mm are available upon request.

Higher stresses are allowed in glass used for reheat pressing.
This has no effect on mechanical processing.

Table 2.3: Limit values of stress birefringence in cut blanks for various dimensions (Ø: diameter or maximum length, d: thickness)

	Stress birefringence		
Dimensions	**Fine annealing [nm/cm]**	**Special annealing (SK) [nm/cm]**	**Precision annealing (SSK) [nm/cm]**
Ø: ≤300 mm d: ≤ 60 mm	≤10	≤6	≤4
Ø: 300–600 mm d: 60– 80 mm	≤12	≤6	≤4

3 Chemical Properties

TIE-30 Chemical properties of optical glass →

The chemical durability of polished glass surfaces depends on the composition of the optical glass. Phosphate crown (PK) and fluor crown (FK) glasses are more sensitive to acidic or alkaline attack compared to borosilicate glasses (e.g. SCHOTT N-BK7®) Therefore, special care has to be taken during the polishing, cleaning and protection of processed surfaces of sensitive glass types.

Please contact us for further information.

The five test methods described below are used to assess the chemical durability of polished glass surfaces.

3.1 Climatic Resistance

Climatic resistance describes the behavior of optical glasses at high relative humidity and high temperatures. A film of white stains can develop on the surface of sensitive glasses that generally cannot be wiped off.

An accelerated procedure is used to test the climatic resistance of the glass, in which polished, uncoated glass plates are exposed to water vapor saturated atmosphere, the temperature of which alternates between 40 °C and 50 °C. This produces a periodic change from moist condensation on the glass surface and subsequent drying.

The glass plates are removed from the climatic chamber after 30 hours of exposure time. The difference in ΔH between the haze before and after testing is used as a measure of the resulting surface change. The measurements are carried out using a spherical hazemeter. Classification is done based on the increase in transmittance haze ΔH after a 30-hour test period. Table 3.1 lists the climatic resistance classes.

Table 3.1: Classification of optical glasses in climatic resistance classes CR 1–4

Climatic resistance class CR	1	2	3	4
Increase in haze ΔH	< 0.3 %	≥ 0.3 % < 1.0 %	≥ 1.0 % < 2.0 %	≥ 2.0 %

The glasses in class CR 1 show no visible attacks after being exposed to climatic change for 30 hours. Under normal humidity conditions during the fabrication and storing of optical glass in class CR 1, no surface attack can be expected. On the other hand, class CR 4 optical glasses should be manufactured and stored with caution because these glasses are highly sensitive to environmental influences.

When storing optical polished elements, we recommend applying a protective coating and/or ensuring that relative humidity is kept as low as possible.

3.2 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 condensation) without vaporization.

The stain resistance class is determined using 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 that contains a few drops of a test solution.

Test solution I: sodium acetate buffer 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 glass is the time that elapses before the first brown-blue stain occurs at a temperature of 25 °C. Changes in color correspond to certain thicknesses of the surface layer that were previously determined on reference samples. A brown-blue change in color indicates a chemical change in the surface layer of 0.1 μm thickness insofar as the glass is able to form layers. Table 3.2 lists the stain resistance classes.

Table 3.2: Classification of optical glasses in stain resistance classes FR 0–5

Stain resistance class FR	**0**	**1**	**2**	**3**	**4**	**5**
Test solution	I	I	I	I	II	II
Time (h)	100	100	6	1	1	0.2
Stain development	no	yes	yes	yes	yes	yes
Color change	no	yes/no	yes	yes	yes	yes

Stain resistance class FR 0 contains all glasses that show virtually no interference colors, even after 100 hours of exposure to test solution I. Glasses in classification FR 5 must be handled with particular care during processing.

3.3 Acid Resistance

Acid resistance describes the behavior of optical glass that comes in contact with larger quantities of acidic solutions (for example: perspiration, laminating substances, carbonated water, etc.). Acid resistance is determined according to ISO 8424 (1996).

Acid resistance is denoted by either a two or a three digit number. The first or first two digits indicate the acid resistance class SR. The last digit, which is separated by a decimal point, indicates the visible surface changes that occurred as a result of exposure. The last digit is discussed in Chapter 3.5.

The time required to dissolve a layer with a thickness of 0.1 µm at 25 °C serves as a measure of acid resistance. Two aggressive solutions are used to determine acid resistance. A strong acid (nitric acid, c = 0.5 mol/l, pH 0.3) is used for the more resistant glass types, whereas glasses with lower acid resistance are exposed to a weak acidic solution with a pH value of 4.6 (sodium acetate buffer). The layer thickness is calculated from the weight loss per surface area and the density of the glass. Table 3.3 lists the acid resistance classes.

Table 3.3: Classification of optical glasses in acid resistance classes SR 1–53

Acid resistance class 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

Class SR 5 forms the transition point between the more acid resistant glasses in SR 1–4 and the more acid sensitive glasses in SR 51–53. Class SR 5 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 h and at a pH value of 4.6 is greater than 10 hours.

3.4 Alkali and Phosphate Resistance

Both test methods are used to classify the resistance of glasses to aqueous alkaline solution in excess and use the same classification scheme.

The alkali resistance indicates the sensitivity of optical glass in contact with warm, alkaline liquids, such as cooling liquids in grinding and polishing processes. Alkali resistance is determined according to ISO 10629 (1996).

Phosphate resistance describes the behavior of optical glass during cleaning with washing solutions (detergents) that contain phosphates. Phosphate resistance is determined according to ISO 9689 (1990).

Both alkali and phosphate resistance are denoted using two digits separated by a decimal point. The first digit lists the alkali resistance class AR or the phosphate resistance class PR, and the decimal indicates the visible surface change that occurs as a result of exposure.

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

The phosphate resistance class PR indicates the time needed to remove a 0.1 µm layer thickness of glass in a solution that contains alkaline phosphate (pentasodium triphosphate $Na_5P_3O_{10}$, c = 0.01 mol/l, pH = 10) at a temperature of 50 °C. The layer thickness is calculated from the weight loss per surface area and the density of the glass. Table 3.4 lists the alkali and phosphate resistance classes.

Glasses in class 1 are more resistant to the test solutions than the glasses in class 4. The digit behind the classification identifies the visible surface change that occurs following exposure. The digits are covered in Chapter 3.5.

Table 3.4: Classification of the optical glasses in alkali resistance classes AR 1–4 and phosphate resistance classes PR 1–4

Alkali resistance class AR, Phosphate resistance class PR	1	2	3	4
Time (h)	>4	1–4	0.25–1	<0.25

3.5 Identification of Visible Surface Changes

Changes in the surface of the exposed samples are evaluated qualitatively with the naked eye. The definition of the digits behind the classification for acid, alkali, and phosphate resistance is as follows:

.0 no visible changes
.1 clear, but irregular surface (wavy, pockmarked, pitted)
.2 staining and/or interference colors (slight, selective leaching)
.3 tenacious thin whitish layer (stronger, selective leaching, cloudy/hazy/dullish surface)
.4 adhere loosely, thick layer, such as insoluble, friable surface deposits (maybe a cracked and/or peelable surface, surface crust, or cracked surface; strong attack)

3.6 Environmental Aspects, RoHS and REACH

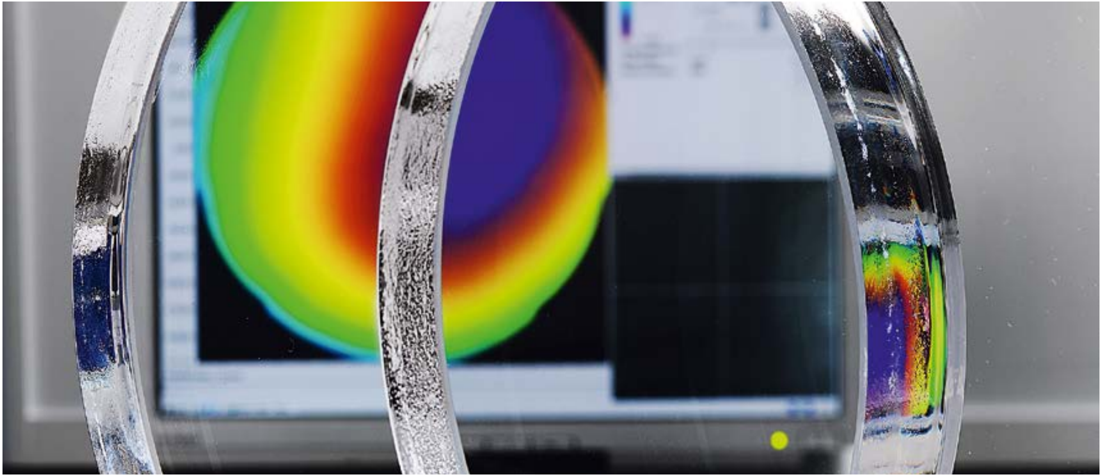
Advanced Optics manufactures, processes and distributes the materials in accordance with SCHOTT's Environmental Protection (IMSU) and Environmental, Health and Safety Management System (EHS) to prevent environmental pollution, conserve natural resources and follow the objectives and procedures of our Quality Management System. The handling of raw materials, melting of batches and hot forming is done in accordance with established safety procedures. Sludge from cutting, grinding and polishing is treated according to the waste and disposal procedures stipulated by local authorities.

All optical materials in this catalog comply with the requirements of the European Directive 2011/65/EU (RoHS II). The optical materials do not contain any mercury (Hg), chromium VI (CrVI), cadmium (Cd) or flame retardants PBB and PBDE whatsoever. "N" and "P" glass types comply with the maximum concentration value of 0.1 % for lead specified in Annex II of RoHS II. Some classical glass types contain lead oxide to ensure the specific optical characteristics of these products. They are in compliance with RoHS due to the exemption 13(a) documented in ANNEX III of RoHS II. On June 4, 2015, by amendment to Annex II of the RoHS Directive, four more substances were restricted: Bis (2-ethylhexyl) phthalate (DEHP), Butyl benzyl phthalate (BBP), Dibutyl phthalate (DBP), Diisobutyl phthalate (DIBP). The amended Directive will come into force from July 22, 2019. All our optical materials already comply with this requirements.

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

Assuring the availability of our optical raw glass portfolio for all customer applications starts with the material development process. All innovations follow a precise substance and legal requirement gate process, to comply with RoHS II, REACH and corresponding global requirements. While updates on legal requirements are traced regionally by external professional specialists in Europe/Africa, America and Asia, SCHOTT is a part of the leading Glass Associations Networks to identify compliance issues early.

To ensure compliance with the European chemicals regulation, REACH, for example, Advanced Optics classified all glass types and carried out numerous chemical analyses and leaching tests in the years 2010 to 2013. While the vast majority of the glasses requires no registration, Advanced Optics identified with this systematic approach a few glasses requiring registration. Accordingly, SCHOTT submitted the registration dossier to the European Chemicals Agency ECHA by the due date of May 31, 2013. We are also carefully observing in close contact with our raw material supplier the list of substances of very high concern (SVHC) and the potential inclusion in the Authorization List (Annex XIV of REACH) to comply with information duties and to ensure further use of these substances in our production processes. This is to ensure that customers as down-stream users are also in compliance with REACH whenever SCHOTT glasses are applied. Please refer in addition to the technical safety information or the safety data sheets provided with the glass of your choice.



4 Mechanical Properties

4.1 Knoop Hardness

TIE-31 Mechanical and thermal properties of optical glass →

Knoop Hardness expresses the amount of surface changes in a material after indentation of a test diamond at a given pressure and time. The standard ISO 9385 describes the measurement procedure for glasses. In accordance with this standard, the values for Knoop Hardness HK are listed in the data sheets for a test force of 0.9807 N (corresponds to 0.1 kp) and an effective test period of 20 s. The test is performed on polished glass surfaces at room temperature. The data for hardness values are rounded off to 10 HK 0.1/20. Micro hardness is a function of the magnitude of the test force and decreases with increasing test force.

4.2 Grindability (ISO 12844)

TIE-31 Mechanical and thermal properties of optical glass →

The grindability according to ISO 12844 allows for a comparison to be made between the grinding processes used with different glasses. Twenty samples of the glass to be classified are ground for 30 seconds in a standardized diamond pellet tool under predetermined conditions. The removed volume of glass is then compared to that of the reference glass, N-SK16. The value for N-SK16 is arbitrarily set to 100.

Classification takes place according to the following scheme:

Table 4.1: Grindability (according to ISO 12844)

Grindability class	Grindability	
HG 1	≤ 30	
HG 2	> 30	≤ 60
HG 3	> 60	≤ 90
HG 4	> 90	≤ 120
HG 5	> 120	≤ 150
HG 6	> 150	
The grindability of N-SK16 is defined as 100.		

According to this scheme, the removal of glass volume during grinding is less in the lower classifications and higher in the upper classifications than for the reference glass N-SK16.

4.3 Viscosity

Glasses run through three viscosity ranges between the melting temperature and room temperature: the melting range, the super cooled melt range, and the solidification range. The viscosity of glass constantly increases during the cooling of the melt ($10^0 - 10^4$ dPa · s). A transition from a liquid to a plastic state can be observed between 10^4 and 10^{13} dPa · s.

The so-called softening point EW identifies the plastic range in which glass parts rapidly deform under their own weight. This is the temperature $T_{10}{}^{7.6}$ at which glass exhibits a viscosity of $10^{7.6}$ dPa·s. The glass structure can be described as solidified or “frozen” above 10^{13} dPa·s. At this viscosity, the internal stress in glass equalizes in approx. 15 minutes.

Another way to identify the transformation range is to observe the change in the rate of relative linear thermal expansion. In accordance with ISO 7884-8, this can be used to determine the so-called transformation temperature T_g. It generally lies close to $T_{10}{}^{13}$.

Precision optical surfaces may deform and refractive indices may change if a temperature of $T_{10}{}^{13} - 200K$ is exceeded during any type of thermal treatment.

TIE-31 Mechanical and thermal properties of optical glass
→

4.4 Coefficient of Linear Thermal Expansion

The typical curve of linear thermal expansion of glass starts near absolute zero with an increase in gradient to approximately room temperature. Then, a nearly linear increase to the beginning of the noticeable plastic behavior follows. The transformation range is characterized by a distinct bending of the expansion curve that results from the increasing structural movement in the glass. Above this range, expansion shows a nearly linear increase again, but with a noticeably greater rate of increase.

Due to the dependence of the coefficient of linear thermal expansion α on temperature, two average linear thermal expansion coefficients α are usually shown for the following temperature ranges:

α (–30 °C; +70 °C) as the relevant information for characterizing glass behavior at room temperature (listed in the Part II Optical Glass – Properties section).

α (+20 °C; +300 °C) as the standard international value for comparison purposes for orientation during the melting process and for temperature change loading (listed in detailed datasheets for our glasses).

Phosphate crown (PK) and fluor crown (FK) glasses are very sensitive to rapid temperature changes during processing, cleaning and handling operations due to their high coefficient of linear thermal change.

5 Thermal Properties

5.1 Thermal Conductivity

TIE-31 Mechanical and thermal properties of optical glass

The range of values for thermal conductivity for glasses extends from 1.38 W/(m · K) (pure quartz glass) to about 0.5 W/(m · K) (glasses with high lead concentrations). The most commonly used silicate glasses have values between 0.9 and 1.2 W/(m · K).

The thermal conductivities shown in the data sheets apply for a glass temperature of 90 °C.

5.2 Heat Capacity

TIE-31 Mechanical and thermal properties of optical glass

The mean isobaric specific heat capacity c_p (20 °C; 100 °C) is listed for some glasses as measured from the heat transfer of a hot glass at 100 °C in a liquid calorimeter at 20 °C. The range of values for c_p (20 °C; 100 °C) and the typical heat capacity c_p (20 °C) for silicate glasses lies between 0.42 and 0.84 J/(g · K).

6 Delivery Quality

6.1 Quality Management and Quality Assurance

The Advanced Optics Business Unit of SCHOTT AG in Mainz operates a global Quality Management System on the basis of ISO 9001/ISO 14001. The certification is performed by Lloyd's Register Quality Assurance, Cologne/Germany.

The research laboratories of Advanced Optics in Mainz for the measurement of physical and chemical properties are accredited by the national accreditation body for the Federal Republic of Germany DAkkS, on the basis of the standard series ISO 17025:2005. Regular round robin tests are performed with the PTB, "Physikalisch-Technische Bundesanstalt" in Braunschweig, Germany. The PTB is a national metrology institute that provides scientific and technical services (*http://www.ptb.de/cms/en.html*), an institution similar to the NIST in the United States.

Optical glass as a technical material requires well-defined reproducible properties that a designer can rely on. Quality assurance of these properties is based on sample-based statistical measurement, partly 100 % measurement, of the optical and internal quality properties during continuous production of optical glass and on customer-specific individual measurement of cut blanks.

Professional work with high-quality materials requires precise knowledge of their properties. Hence, as Fraunhofer has already realized, progress in the production of optical glasses and their applications is always limited by the measurement capabilities. Ever growing quality demands for industrial and research applications require constant improvement of measurement technology, which is still going on.

6.2 Standard Delivery Quality

If no special quality steps are requested, the glass will be delivered in the refractive index/Abbe number Step 3 with a standard test report. The standard test report refers to a delivery lot that fulfills the standard variation tolerance. The refractive index variation from batch to batch within a lot will not exceed $\pm 1 \cdot 10^{-4}$ ($\pm 2 \cdot 10^{-4}$ for pressings, if requested). The glass is tested for bubbles and inclusions, striae, and stress birefringence.

Production of optical glass is a stable process, with only small variations in the chemical, mechanical and thermal properties of the glass. These properties are statistically controlled data sheet reference values and not measured individually upon order.

6.3 Enhanced Delivery Quality

In addition to our standard delivery quality Table 6.1. SCHOTT will offer enhanced delivery qualities for various forms of supply.

Table 6.1: Additional quality steps for various forms of supply

	Glass for hot processing	Pressings	Fine annealed glass	Cut blanks
Refractive index – Abbe number steps	2, 1	2, 1, 0.5	2, 1, 0.5	2, 1, 0.5
Test certificates	Annealing schedule	Standard (S)	Standard (S)	Standard (S)
Measurement accuracy, measurement ranges	With data on the annealing rates for the achievable refractive index – Abbe number steps after fine annealing	If variation tolerance is requested	Standard with enhanced accuracy (SE)	Standard with enhanced accuracy (SE), precision (PZ), dn/dT (DNDT)
Refractive index scattering	S0, S1	LH1, LH2	S0, S1	S0, S1
Homogeneity	–	upon request	–	H1–H5
Stress birefringence	–	SK	SK	SK, SSK
Striae	–	–	–	VS*
Bubbles/inclusions	–	VB, EVB	–	VB, EVB
Remarks			At least one surface can be worked	Striae and homogeneity measured in the same direction

* 1–3 test directions possible

The quality steps listed within a form of supply can be combined with one another. However, melts that are suited to various combinations are not always available.

We recommend checking availability with us as early as possible.

Requirements that exceed the quality steps mentioned can also be met. Please ask for further details.

7 Forms of Supply and Tolerances

Advanced Optics masters the entire value chain: from customer-specific glass development and its production all the way to high-precision optical product finishing, processing and measurement. By leveraging our extensive capabilities in the area of processing (polishing, coating, bonding, etc.), we offer a wide variety of custom-made optical components such as lenses (aspherical, spherical, cylindrical), prisms, mirrors, wafers, substrates and more.

Here, you will find a selection of available supply forms:

7.1 Raw Glass

7.1.1 Blocks

Blocks have up to five unworked, as-cast surfaces. Usually, at least one surface has been worked.

The edges are rounded. Blocks are fine annealed and thus suitable for cold working.

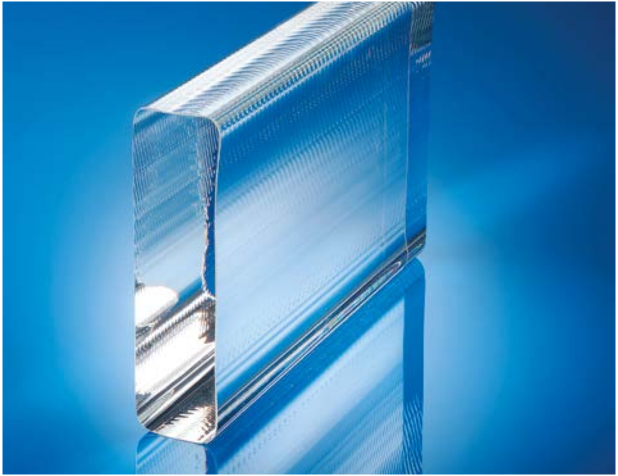
Described by: *length, width, thickness*

7.1.2 Strips

Strips normally have unworked or ground surfaces and broken or cut ends.

Strips are either coarse annealed or fine annealed. Coarse annealed strips are only suitable for reheat pressings.

Described by: *length, width, thickness*



7.2 Cut Blanks

7.2.1 Plates

Plates are quadrilateral fabricated parts.

All six sides are worked; the edges have protective bevels.

Described by: *length, width, thickness*

We achieve surface roughnesses of $R_a = 20-25\ \mu m$ with standard processing. Plates with closer dimensional tolerances and finer surfaces are possible upon request.

Table 7.1: Dimensional tolerances and minimum dimensions for plates

Maximum edge length [mm]	Admissible tolerances				Minimum thickness[1) [mm]
	For edge length		For thickness		
	Standard [mm]	Precision [mm]	Standard [mm]	Precision [mm]	
> 3– 80	±0.2	±0.1	±0.3	±0.15	2
> 80– 120	±0.3	±0.15	±0.5	±0.25	4
> 120– 250	±0.5	±0.25	±0.5	±0.25	6
> 250– 315	±0.9	±0.45	±0.8	±0.4	8
> 315– 400	±1.2	±0.6	±0.8	±0.4	8
> 400– 500	±1.3	±0.65	±0.8	±0.4	20
> 500– 630	±1.5	±0.75	±0.8	±0.4	20
> 630– 800	±1.8	±0.9	±0.8	±0.4	20
> 800–1000	±2.0	±1.0	±0.8	±0.4	20
>1000	Inquire	Inquire	Inquire	Inquire	

1) Lower thicknesses than listed are possible. Please ask for details.

7.2.2 Round plates

Round plates are cylindrical parts for which the diameter is larger than the thickness. Round plates are machined on all surfaces.

Described by: *diameter, thickness*

We achieve surface roughnesses of R_a = 20 – 25 μm with standard processing. Round plates with closer dimensional tolerances and finer surfaces are possible upon request.

Table 7.2: Dimensional tolerances and minimum dimensions for round plates

	Admissible tolerances				
	For diameter		For thickness		
Diameter [mm]	Standard [mm]	Precision [mm]	Standard [mm]	Precision [mm]	Minimum thickness[1)] [mm]
> 3– 80	±0.2	±0.1	±0.3	±0.15	2
> 80– 120	±0.3	±0.15	±0.5	±0.25	4
> 120– 250	±0.3	±0.15	±0.5	±0.25	6
> 250– 500	±0.5	±0.25	±0.8	±0.4	20
> 500– 800	±0.8	±0.4	±0.8	±0.4	20
> 800–1250	±1.0	±0.5	±0.8	±0.4	40
>1250	Inquire	Inquire	Inquire	Inquire	

1) Lower thicknesses than listed are possible. Please ask for more details.

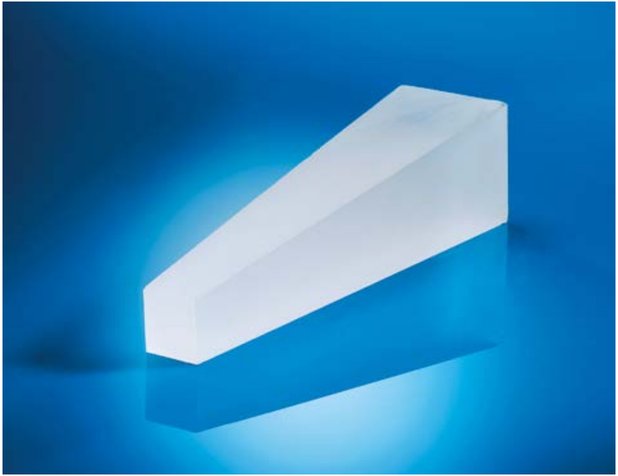
7.2.3 Worked rods

Worked rods are cylindrical parts that are machined on all sides. The length of a rod is always greater than its diameter.

Described by: *diameter, length*

Table 7.3: Dimensions and tolerances for worked rods in the 6–80 mm diameter range

Diameter [mm]	Standard tolerance [mm]	Tolerances, drilled and rounded according to ISO 286				Length range [mm]	Tolerance for length [%]
		[mm]	[mm]	[mm]	[mm]		
6–10	±0.2	h11 +0/–0.09	h10 +0/–0.058	h9 +0/–0.036	h8 +0/–0.022	max. 130	±2
>10–18	±0.2	h11 +0/–0.11	h10 +0/–0.070	h9 +0/–0.043	h8 +0/–0.027	max. 130	±2
>18–30	±0.2	h11 +0/–0.13	h10 +0/–0.084	h9 +0/–0.052	h8 +0/–0.033	max. 130	±2
>30–50	±0.2	h11 +0/–0.16	h10 +0/–0.100	h9 +0/–0.062	h8 +0/–0.039	max. 130	±2
>50–80	±0.3	h11 +0/–0.19	h10 +0/–0.120	h9 +0/–0.074		max. 130	±2



7.2.4 Cut prisms

Cut prisms are prisms produced by cutting and can be ground on all sides.

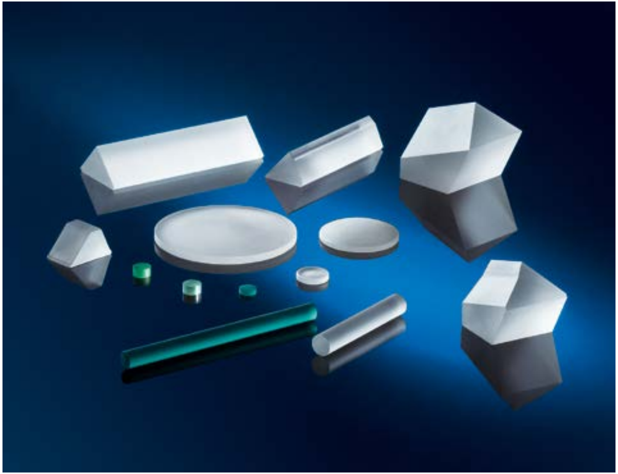
Equilateral and non-equilateral prisms can be produced in various forms (ridge, penta, triple prisms …) using different fabrication technologies.

Described by: *drawing*

Table 7.4: Dimensions and tolerances for cut prisms

Maximum edge length [mm]	Tolerances for dimensions [mm]	Tolerances for width [mm]
<50	+1.0/–0	±0.5
50–100	+1.5/–0	±1.0
>100	+2.0/–0	±1.0

7.3 Pressings



7.3.1 Pressed blanks

Pressed blanks are hot formed parts with mainly round cross sections, defined radii and bevels.

Described by:
diameter, center thickness, radius 1, radius 2, bevels

Table 7.5: Dimensions and tolerances for pressed blanks

Diameter [mm]	Tolerances for diameter [mm]	Tolerances for thickness [mm]	Minimum center thickness [mm]	Minimum edge thickness [mm]	Maximum edge thickness [mm]
5– 18	±0.075	±0.3	2	1	0.6 ·Ø
> 18– 30	±0.11	±0.3	3	1.5	0.45·Ø
> 30– 60	±0.14	±0.3	4	3	0.4 ·Ø
> 60– 90	±0.175	±0.3	5	4	0.3 ·Ø
> 90–120	±0.25	±0.4	6	5	0.3 ·Ø
>120–140	±0.3	±0.4	7	5	0.3 ·Ø
>140–180	±0.4	±0.4	7	6	0.3 ·Ø
>180–250	±0.5	±0.5	10	8	0.3 ·Ø
>250–320	±0.6	±0.6	10	8	0.3 ·Ø

7.3.2 Pressed prisms

Pressed prisms are hot formed parts with angled, prismatic shapes.

Other dimensions are possible upon request.

Described by: *dawing*

Table 7.6: Dimensions and tolerances for pressed prisms

Maximum edge length [mm]	Tolerances for edge length [mm]	Tolerances for center thickness [mm]	Angular	Socket [mm]
5– 30	±0.2	±0.3	±0.5°	2
> 30– 60	±0.3	±0.4		2
> 60– 90	±0.4	±0.5		2.5
> 90–150	±0.5	±0.5		2.5
>150–180	±0.7	±0.7		3
>180–305	±1.0	±1.0		4

7.4 Optical Glass Rods for Miniaturized Ball Lenses, Discs & More!

SCHOTT offers the widest range of rods with different geometries, formats and materials.

Optical glass rods from SCHOTT for applications that use small optical components such as ball lenses, rod lenses, aspheres and discs are manufactured with the help of different unique processes.

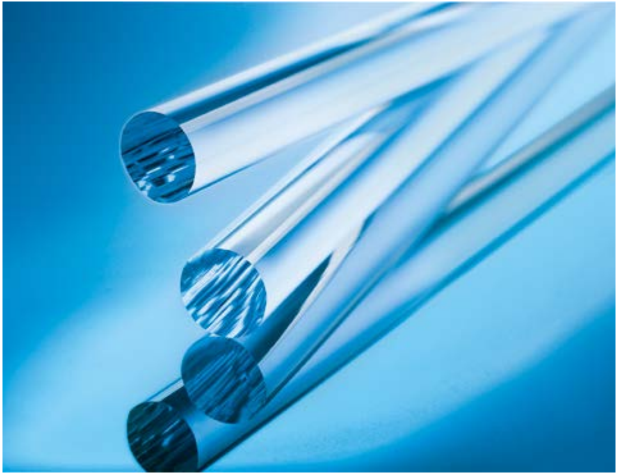


Table 7.7: Optical glass rods – specifications*

	Fire-polished surface		Matt surface	
Description	**Standard quality**	**Premium quality**	**Standard quality**	**Premium quality**
Diameter/tolerance	±5% of nominal diameter	±3% of nominal diameter	±0.1 mm	±0.05 mm
Straightness deviation	max. 0.1 mm/100 mm	max. 0.1 mm/100 mm	max. 0.05 mm/100 mm	max. 0.03 mm/100 mm
Length tolerance	+5 mm	+2 mm	+5 mm	+2 mm
Diameter range	<1.0–7.0 mm	<1.0–7.0 mm	2.0–12.5 mm	2.0–12.5 mm
Surface quality	fire-polished	fire-polished	matt	matt
Length	up to 1000 mm		up to 150 mm	

* Reference to round shape and glass type P-LASF47

8 Optical Glasses for Precision Molding

Precision molding technology for the direct pressing of aspherical lenses or freeform surfaces in general has become more and more important in recent years all over the world. During the precision molding process, a glass preform with exceptionally high surface quality is shaped into its final aspherical geometry, while conserving the surface quality of the preform. The molding process is a low temperature molding process with temperatures that typically range between 500 °C and 700 °C. Low temperature processes help to extend the operating lifetime of the mold material.

“P” glasses are newly developed low transformation temperature glasses especially for use in precision molding. The letter “P” indicates that these glasses are produced exclusively for precision molding.

TIE-40 Optical glass for precision molding →

In addition, several traditional optical glasses have been identified to be suitable for precision molding, mainly because of their low glass transition temperatures.

Glasses for precision molding in general are coarse annealed glasses. They are produced in refractive index/Abbe number Step 3/3 based on a 2K/h reference annealing rate. The actual refractive index of the glass within the delivery lot will differ from this value, however.

The rapid cooling rate of a precision molding process leads to an index drop that lowers the refractive index of the glass significantly compared to the initial value. The index drop is defined as the difference between the refractive index of the glass after molding and the initial refractive index based on a 2K/h reference annealing rate.

The Part II Optical Glass – Properties section contains the n_d and ν_d values after molding using a SCHOTT reference process. Some of these values are preliminary data based on a theoretical reference annealing rate of 5000 K/h. The catalog value nd serves as an initial refractive index based on a reference annealing rate of 2 K/h to calculate the index drop.

Furthermore, the index drop can be calculated based on a higher initial reference annealing rate of 25 K/h. For this purpose, the n_d reference value based on an annealing rate of 25 K/h is listed.

The index drop for a given glass type depends on the specific process and geometry of the part and will differ slightly from the values displayed in the Part II Optical Glass – Properties section.

If the refractive index after molding does not meet specific customer requirements, specific index adjustments to the given process conditions are possible upon request.

The optical glasses available that are suited for use in precision molding are displayed in the Part II Optical Glass – Properties section of this catalog, which contains the newly developed “P” glasses and the traditional glasses that are suitable for precision molding. The Part II Optical Glass – Properties section on low T_g glasses also contains additional information, such as acid resistance according to JOGIS (Japanese Optical Glass Industrial Standard), grindability (abrasion) according to JOGIS and the yield point/sag temperature of the glass.

9 Product Range of Optical Glasses

9.1 Preferred Glasses

The glasses listed in the first part of the data section are preferred glasses. They are produced before any specific customer orders have been received and are usually kept in stock for immediate delivery. We can guarantee a reliable long-term supply of these glasses. Preferred glasses are thus recommended for the use of designs in new optical systems and listed in our so-called positive list of optical glasses. The current version of the positive list of optical glasses can be found on our website *(http://www.schott.com/advanced_optics/english/download/index.html).*

9.2 Inquiry Glasses

The second part of the Part II Optical Glass – Properties section is comprised of inquiry glasses that are produced on a regular basis in response to specific requests. With some of these glasses, we might have stock available from previous long running projects. However, stock is not generated on purpose without receiving orders from our customers. But even if they are not available in stock, glasses will be manufactured and delivered upon request.

10 Collection of Formulas and Wavelength Table

Relative partial dispersion $P_{x,y}$ for the wavelengths x and y based on the blue F and red C hydrogen line

$$P_{x,y} = (n_x - n_y)/(n_F - n_C) \qquad (10.1)$$

or based on the blue F′ and red C′ cadmium line

$$P'_{x,y} = (n_x - n_y)/(n_{F'} - n_{C'}) \qquad (10.2)$$

Linear relationship between the Abbe number and the relative partial dispersion for "normal glasses"

$$P_{x,y} \approx a_{xy} + b_{xy} \cdot \nu_d \qquad (10.3)$$

Deviation ΔP from the "normal lines"

$$P_{x,y} = a_{xy} + b_{xy} \cdot \nu_d + \Delta P_{x,y} \qquad (10.4)$$

$$\Delta P_{C,t} = (n_C - n_t)/(n_F - n_C) - (0.5450 + 0.004743 \cdot \nu_d) \qquad (10.5)$$

$$\Delta P_{C,s} = (n_C - n_s)/(n_F - n_C) - (0.4029 + 0.002331 \cdot \nu_d) \qquad (10.6)$$

$$\Delta P_{F,e} = (n_F - n_e)/(n_F - n_C) - (0.4884 - 0.000526 \cdot \nu_d) \qquad (10.7)$$

$$\Delta P_{g,F} = (n_g - n_F)/(n_F - n_C) - (0.6438 - 0.001682 \cdot \nu_d) \qquad (10.8)$$

$$\Delta P_{i,g} = (n_i - n_g)/(n_F - n_C) - (1.7241 - 0.008382 \cdot \nu_d) \qquad (10.9)$$

The position of the normal lines was determined based on value pairs of the glass types K7 and F2.

Sellmeier dispersion formula

$$n^2(\lambda)-1 = B_1\,\lambda^2/(\lambda^2-C_1)+B_2\,\lambda^2/(\lambda^2-C_2)+B_3\,\lambda^2/(\lambda^2-C_3) \qquad (10.10)$$

When calculating the refractive index using the Sellmeier coefficients from the SCHOTT data sheets, the wavelength λ needs to be entered in units of µm.

Change in refractive index and Abbe number during annealing at different annealing rates

$$n_d(h_x) = n_d(h_0)+m_{nd}\cdot\log(h_x/h_0) \qquad (10.11)$$

$$\nu_d(h_x) = \nu_d(h_0)+m_{\nu d}\cdot\log(h_x/h_0) \qquad (10.12)$$

$$m_{\nu d} = (m_{nd}-\nu_d(h_0)\cdot m_{nF-nC})/((n_F-n_C)+2\cdot m_{nF-nC}\cdot\log(h_x/h_0)) \qquad (10.13)$$

h_0	Beginning annealing rate
h_x	New annealing rate
m_{nd}	Annealing coefficient for the refractive index, depending on glass type
$m_{\nu d}$	Annealing coefficient for the Abbe number, depending on glass type
m_{nF-nC}	Annealing coefficient for the principal dispersion, depending on glass type

Measurement accuracy of the Abbe number

$\sigma_{\nu d} \approx \sigma_{nF-nC} \cdot \nu_d / (n_F - n_C)$ (10.14)

Spectral internal transmittance

$\tau_{i\lambda} = \Phi_{e\lambda} / \Phi_{i\lambda}$ (10.15)

Spectral transmittance

$\tau_{\lambda} = \tau_{i\lambda} \cdot P_{\lambda}$ (10.16)

P_{λ} factor of reflection

Fresnel reflectivity for a light beam with normal incidence, irrespective of polarization

$R = ((n-1)/(n+1))^2$ (10.17)

Reflection factor that considers multiple reflections

$P = (1-R)^2/(1-R^2) = 2n/(n^2+1)$ (10.18)

n Refractive index for the wavelength λ

Converting of internal transmittance to another layer thickness

$\log \tau_{i1} / \log \tau_{i2} = d_1 / d_2$ or (10.19)

$\tau_{i2} = \tau_{i1}^{(d_2/d_1)}$ (10.20)

τ_{i1}, τ_{i2} Internal transmittances at thicknesses d_1 and d_2

Stress birefringence, difference in optical path

$\Delta s = 10 \cdot K \cdot d \cdot \sigma$ in nm (10.21)

K Stress optical constant, dependent on glass type in 10^{-6} mm²/N
d Length of light path in the sample in cm
σ Mechanical stress (positive for tensile stress) in N/mm² (= MPa)

Homogeneity from interferometrically measured wave front deviations

$\Delta n = \Delta W / (2 \cdot d)$ (10.22)

$= \Delta W[\lambda] \cdot 632.8 \cdot 10^{-6} / (2 \cdot d[mm])$

when listing the wave front deformation in units of the wavelength and a test wavelength of 632.8 nm (Helium-neon gas laser)

ΔW	Wave front deformation with double beam passage (Fizeau interferometric testing)
d	Thickness of test piece

Note: The formulas have been chosen carefully and listed.
Nevertheless, SCHOTT cannot be held responsible for errors resulting from their use.

Table 10.1: Wavelengths for selecting frequently used spectral lines

Wavelength [nm]	Designation	Spectral line used	Element
2325.42		Infrared mercury line	Hg
1970.09		Infrared mercury line	Hg
1529.582		Infrared mercury line	Hg
1060.0		Neodymium glass laser	Nd
1013.98	t	Infrared mercury line	Hg
852.11	s	Infrared cesium line	Cs
706.5188	r	Red helium line	He
656.2725	C	Red hydrogen line	H
643.8469	C′	Red cadmium line	Cd
632.8		Helium-neon gas laser	He-Ne
589.2938	D	Yellow sodium line	Na
		(center of the double line)	
587.5618	d	Yellow helium line	He
546.0740	e	Green mercury line	Hg
486.1327	F	Blue hydrogen line	H
479.9914	F′	Blue cadmium line	Cd
435.8343	g	Blue mercury line	Hg
404.6561	h	Violet mercury line	Hg
365.0146	i	Ultraviolet mercury line	Hg
334.1478		Ultraviolet mercury line	Hg
312.5663		Ultraviolet mercury line	Hg
296.7278		Ultraviolet mercury line	Hg
280.4		Ultraviolet mercury line	Hg
248.3		Ultraviolet mercury line	Hg

11 Technical Information – TIE

TIE available
→

The relevant TIEs can be found under
http://www.schott.com/advanced_optics/english/knowledge-center/technical-articles-and-tools/tie.html

Title		
TIE-25:	Striae in optical glass	(Chapter 2.1)
TIE-26:	Homogeneity of optical glass	(Chapter 1.4)
TIE-27:	Stress in optical glass	(Chapter 2.3)
TIE-28:	Bubbles and inclusions in optical glass	(Chapter 2.2)
TIE-29:	Refractive index and dispersion	(Chapter 1.1)
TIE-30:	Chemical properties of optical glass	(Chapter 3)
TIE-31:	Mechanical and thermal properties of optical glass	(Chapter 4.1, 4.2, 4.4, 5.1, 5.2)
TIE-35:	Transmittance of optical glass	(Chapter 1.5)
TIE-40:	Optical glass for precision molding	(Chapter 8)
TIE-42:	Radiation resistant optical glasses	(Foreword & Overview)

12 SCHOTT Advanced Optics at a glance

SCHOTT Advanced Optics, with its extensive 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 Advanced Optics – Your Partner for Excellence in Optics.

This chapter will give you an overview of the SCHOTT Advanced Optics product portfolio. It consists of the following products:

- Optical Materials, such as optical glass, HT- & HTultra glasses, active & passive laser glass, sapphire, infrared ceramics and infrared chalcogenide glasses
- Optical Components, such as lenses, plano-plano optics, and prisms
- Optical Filters, e.g. NIR cutoff filters, contrast enhancement filters, optical filter glass as well as interference filters

OPTICAL MATERIALS

Optical Glass

More than 120 high-quality optical glasses

For more than 130 years, SCHOTT Advanced Optics has been offering a large portfolio of high-quality optical glasses to meet the needs of a broad variety of optical as well as industrial applications, ranging from consumer products to high-power optics at the cutting edge of research.

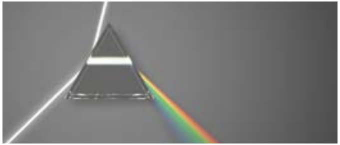
Our range of optical glasses includes environmentally friendly N-glasses, glasses suited to precision molding (low T_g Glass) as well as classic glass types with lead oxide as an essential component for outstanding optical properties.

In addition, we offer versions of our glasses with a particularly high transmission (HT & HTultra Glasses) and with high homogeneity.

HT & HTultra Glass

Optical glasses with ultra-high transmittance

As part of its extensive portfolio of optical glass types, SCHOTT has been offering special glass versions that are known for their superior transmittance and which are particularly well-suited to digital projection and high-power optical systems.



XLD Glass

Optical glasses with extreme low dispersion

To indicate optical glasses with the highest Abbe numbers $\nu_d > 90$, SCHOTT gives such glasses the suffix XLD (eXtreme Low Dispersion). Due to their unique partial dispersion, these glasses offer outstanding apochromatic correction capabilities. These fluorophosphate glasses were developed for excellent processing properties.

High Homogeneity Glass

Extremely high homogeneity for large high-precision optical lenses

Optical glasses that are used in high power laser and astronomical applications require extremely high homogeneity. SCHOTT manufactures high-quality glasses up to homogeneity class H5 and now offers several glass types up to quality level H4 that are available from stock.

Low T_g Glass

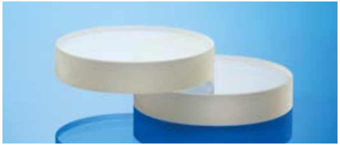
Optical glass suitable for use in precision molding

Precision molding is a technology for the volume production of complex lenses, e.g. aspheres, for various applications such as digital cameras and smartphones, telecommunications, lens arrays or microscopy applications.

i-line Glass

With high UV transmittance at 365 nm and high reflective index homogeneity

i-Line glasses are optical glass types named after the i wavelength, which offer both high UV transmittance at 365 nm and high refractive index homogeneity. These glass types can be found in lithography applications such as i-line steppers and wafer scanners.



Radiation Resistant Glass

With high radiation resistance and different dispersion properties

SCHOTT Advanced Optics offers a variety of radiation resistant glass types with different dispersion properties. These glass types are well-suited to use in surroundings with high radioactivity. Radiation resistant glass is provided in the form of cut blanks, pressings, and rods as well as finished optical components.

Radiation Shielding Glass

Extraordinary optical properties and high radiation resistance against ionizing radiation

Specially developed radiation shielding glasses in the density range from 2.5 to 5.2 g/cm^3 covering a variety of optical and shielding properties, allowing for the custom design of radiation shielding windows with a perfect combination of high shielding capability and resistance against ionizing radiation.

Sapphire

One of the hardest, most durable and scratch resistant materials

Sapphire offers a broad transmission range from UV to mid-infrared wavelengths (250 – 5000 nm). This material is capable of withstanding extreme environmental conditions and fluctuations in temperature. SCHOTT offers sapphire in processed shapes according to the customer's specifications.

Infrared Chalcogenide Glass

Various IR glasses with excellent transmittance in SWIR, MWIR, LWIR

Infrared glasses offer excellent transmission in the shortwave, midwave, and longwave IR range. These glasses encompass the common IR transmission bands 3 – 5 µm and 8 – 12 µm, but can transmit as low as 0.7 µm. These glasses are used for night vision systems, thermal cameras, in medial applications, and much more.

Infrared Ceramic

For advanced imaging, sensing and security

Zinc Sulfide (ZnS) is a key material for broadband infrared windows, domes and optics. No other material offers the combination of optical properties and environmental resistance. However, conventional zinc sulfide is produced through chemical vapor deposition (CVD) and does not take full advantage of the material's properties. SCHOTT has developed a ceramic process to produce polycrystalline zinc sulfide (SCHOTT IRC-1) which has markedly improved optical and mechanical performance when compared to CVD-processed materials.

OPTICAL COMPONENTS

Optical Components

Different products for various applications

SCHOTT offers a broad range of different component types for applications in optics, lithography and science. Known for its cutting-edge innovations, its highest product quality and its service excellence, Advanced Optics is integrated from material development to finishing operations.

We master the entire value chain! Processed products include precision-molded, polished and coated aspherical lenses, prisms, optical glass filters and interference filters as well as precision components, such as CNC-processed parts, plane-parallel substrates and wafers.

Further details about our comprehensive portfolio of high precision optical components can be found online at: *http://www.schott.com/advanced_optics/english/products/optical-components/index.html*

Aspherical Lenses

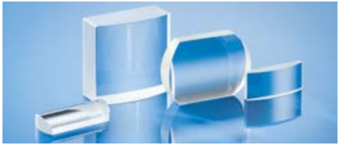
Aspheres for superior image quality

Due to their unique surface structure, aspherical lenses eliminate monochromatic aberrations and therefore deliver superior overall image quality. They are being used to replace multi-spherical element assemblies and enable a more compact design.

Spherical Lenses

As singlets, doublets, and triplets in different shapes

Spherical lenses are used in many different applications, such as cameras, projectors and microscopes, to collect, focus and diverge light and are often components of lens systems that perform an achromatic function.



Cylindrical Lenses

Wide variety of specific lenses

Cylindrical lenses have a spherical radius in one direction. This enables the light to be focused in one axis. A point of light can thus be stretched into a single line. Cylindrical lenses can be used in a variety of different applications, including bar code scanning or laser projection, for example.

Prisms

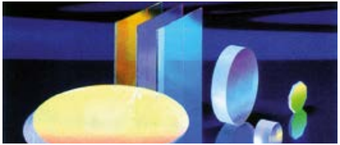
Perfect custom optical components

Prisms are transparent optical elements with flat polished surfaces that refract, reflect or disperse light. They can be positioned rather easily inside an optical system and offer excellent thermal stability. Total internal reflection is possible to avoid light loss in the optical path.

Windows & Substrates

Highest precision made of various materials

Substrates are components that serve as the base to be coated to produce products like interference filters. Windows are transparent, mostly plano-plano parallel polished and/or coated components that are used in optical systems to achieve highly-efficient, distortion-free light and perfect image transmission.



Coating

Variety of types of coating

Design and manufacturing of customized coatings with extensive capabilities to deposit thin films onto glass and other substrates for spectral wavelengths between 200 nm and 3000 nm using different technologies (e.g. ion assisted deposition, IBS & magnetron sputtering).

CNC Machining

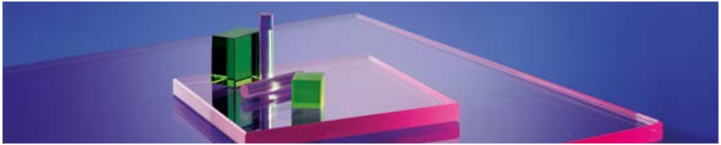
Precisely manufactured parts

A wide variety of high-performance machines make it possible to produce almost any conceivable geometry. This offers our customers newfound freedom with respect to designing their products. Furthermore, SCHOTT's own inventory of optical raw materials also makes it possible for us to produce more quickly and cost effectively.

Assembly

Mounting of optics

Customized mounts (e.g. positioning, optical centering, etc.) which can be assembled in a cleanroom environment. Furthermore, all the necessary measuring instruments include 3D optical measurements and profilometers, interferometers are in place.



Active Glass for Laser Applications

SCHOTT offers a wide range of active laser glasses for high power, ultra-short pulse, laser range finding and medical applications. These entire glasses can be tailored to a specific application, e.g. for flash lamp or diode pumping. Platinum-particle-free melting developed at SCHOTT enables the highly fluent operation of phosphate laser glass components without laser-induced damage; large volume laser slabs in apertures of up to 400 mm and in mass quantities enable high energy storage for the inertial confinement fusion program; and zig-zag slabs and large diameter laser rods produced in the highest optical quality and homogeneity help to renable high performance for laser systems which process materials.

The glass is obtainable with the use of active laser rods, slabs or disks. AR and HR coatings for all laser wavelengths with high LIDT are obtainable. All components are manufactured per customers' specifications and can be polished up to λ/10 flatness.

To complement this, SCHOTT offers a broad range of passive laser components such as mirrors and windows.

Active Materials

- Silicate-based glass LG-680
- Phosphate based glasses
  LG-7 Series, LG-9 Series, APG, BLG

Active Components

- Rods
- Slabs
- Bars coated/uncoated

Passive Materials

- Passive laser glasses S-7 Series
- Wide range of optical glasses
  and special variants
  (e.g. SCHOTT N-BK7®)
- ZERODUR®

Passive Components

- Aspherical lenses
- Laser mirrors & windows
- Beamsplitters & polarizers
- Polished prisms
- Optical filters coated/uncoated

OPTICAL FILTERS

Optical Filter Glass

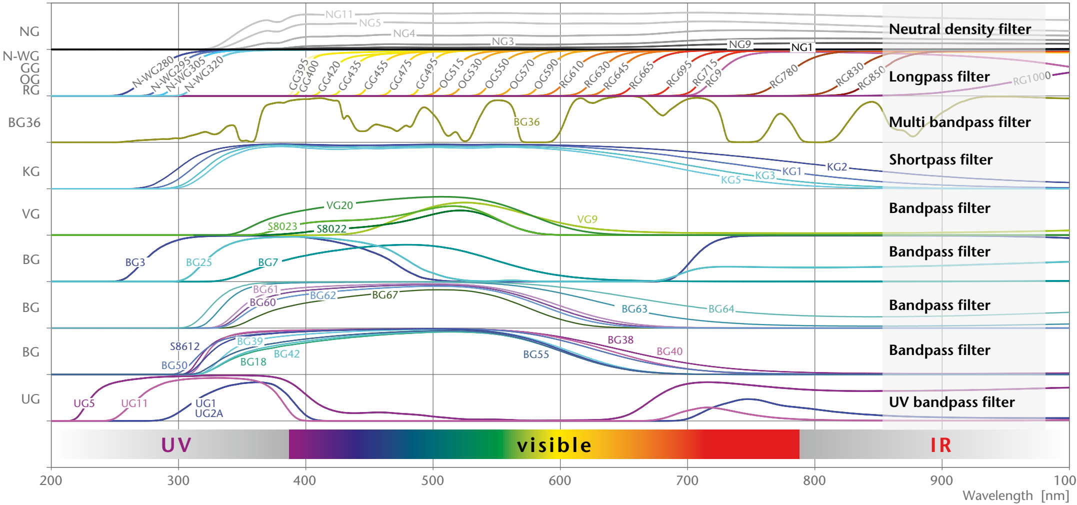
Colored filter glasses from the entire spectrum

SCHOTT Advanced Optics offers one of the world's broadest portfolios of optical filter glasses for a full spectral solution that meets your requirements. These filter glasses enable applications in analytics, photography, medical technology and laser protection.

Optical filter glass is known for its selective absorption in the visible wavelength range. Optical filter glasses appear to be colored if their filter effect lies within the visible light spectrum. Numerous colorants with different concentrations and many different base glasses have been developed to facilitate the development of an assortment of filters, some with extreme filter properties, in the largest possible spectral region.

SCHOTT's optical filter glasses include the following filter types in the wavelength range above 200 nm:
- Bandpass filters
- Longpass filters
- Shortpass filters
- Neutral density filters
- Contrast enhancement filters
- Multiband filters
- Photo filters

Internal Transmittance of SCHOTT Optical Filter Glass



Interference Filters

Coated filters for the entire spectral range

Interference filters that use the interference effect to obtain a spectral function are manufactured by depositing thin layers with different refractive indices onto a substrate. These filters are used for applications in medical technology, for analytics in measurements, environmental, biotech, chemical and medical, fluorescence microscopy, and more.

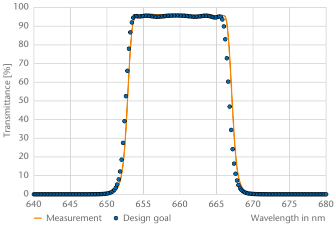
SCHOTT supplies a range of geometries and sizes of interference filters within the spectral range of 200 nm to 3000 nm. These products are developed, designed and manufactured according to customer specifications. Interference filters offer excellent climatic resistance and extremely stable spectral characteristics with respect to temperature and humidity changes.

Our product range comprises various types of interference filters:
bandpass filters, edge filters, notch filters, UV-bandpass filters, hard and scratch-resistant filters, i-line filters, VERIL linear variable filters, optimized AR and broadband-AR coated filters, beamsplitters, neutral density filters, mirror coatings (dichroic or metallic), and black absorber coatings.

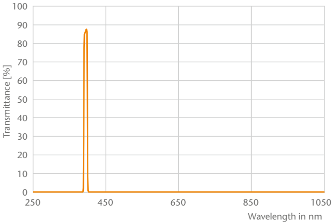
The whole process chain for interference filters from a single source.

Custom-made designs are calculated by a whole group of scientists and engineers. Substrates are polished and transferred directly to the coating. An extensive clean-room production facility with different coating technologies can meet almost any requirement. Our sophisticated set of measurement equipment guarantees perfect quality control for any feature of the filter.

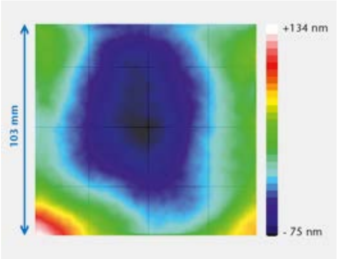
Perfect consistency between measurement and production



Bandpass with broad blocking T < 10^{-5}



Low transmitted wavefront distortion



Change Index – Part II Optical Glass – Properties **Section**

SCHOTT Advanced Optics is committed to supporting our customers by continuously improving our existing product offerings, as well as expanding our portfolio. We are also committed to providing detailed information regarding the properties of our glasses, therefore enabling our customers to perform their own work more effectively. As a result, we've created the following table to identify pertinent changes to our optical glasses, as well as additions to our line. All relevant changes are additionally marked as well in blue in our Part II Optical Glass – Properties Section. If you have any questions regarding these products, please contact one of our representatives directly.

N-FK58	New glass
N-LAK33A	Inquiry glass
P-SF67	Inquiry glass

Optical Glass 2016

Properties

Glass type	n_d	ν_d	$n_F - n_C$	n_e	ν_e	$n_{F'} - n_{C'}$	n_r	n_C	$n_{F'}$	n_g	n_h
N-FK58** 456909.365	1.45600	90.90	0.005017	1.45720	90.47	0.005053	1.45358	1.45446	1.45976	1.46216	1.46436
N-FK5* 487704.245	1.48749	70.41	0.006924	1.48914	70.23	0.006965	1.48410	1.48535	1.49266	1.49593	1.49894
N-FK51A* 487845.368	1.48656	84.47	0.005760	1.48794	84.07	0.005804	1.48379	1.48480	1.49088	1.49364	1.49618
N-PK51* 529770.386	1.52855	76.98	0.006867	1.53019	76.58	0.006923	1.52527	1.52646	1.53372	1.53704	1.54010
N-PK52A 497816.370	1.49700	81.61	0.006090	1.49845	81.21	0.006138	1.49408	1.49514	1.50157	1.50450	1.50720
N-PSK3 552635.291	1.55232	63.46	0.008704	1.55440	63.23	0.008767	1.54811	1.54965	1.55885	1.56302	1.56688
N-PSK53A* 618634.357	1.61800	63.39	0.009749	1.62033	63.10	0.009831	1.61334	1.61503	1.62534	1.63007	1.63445

*** Available in step 0.5 ** SCHOTT XLD Glass (eXtreme Low Dispersion)**

$P_{g,F}$	$\Delta P_{g,F}$	CR	FR	SR	AR	PR	α (–30/+70)	T_g	$T_{10^{7.6}}$	ρ	HK	HG	τ_i (10/400)	FC
0.5347	0.0438	1	1	52.3	3.3	4.3	13.7	445	508	3,65	372		0.996	33/--
0.5290	0.0036	2	1	4	2	2.3	9.2	466	672	2.45	520	3	0.998	30/26
0.5359	0.0342	1	0	52.3	2.2	4.3	12.7	464	527	3.68	345	6	0.997	34/28
0.5401	0.0258	1	0	52.3	3.3	4.3	12.4	487	568	3.86	415	6	0.994	34/29
0.5377	0.0311	1	0	52.3	3.3	4.3	13.0	467	538	3.70	355	6	0.997	34/28
0.5365	–0.0005	3	0	2.2	2	2	6.2	599	736	2.91	630	2	0.994	33/28
0.5424	0.0052	1	1	53.3	2.3	4.3	9.6	606	699	3.57	415	6	0.985	36/31

Glass type	n_d	ν_d	$n_F - n_C$	n_e	ν_e	$n_{F'} - n_{C'}$	n_r	n_C	$n_{F'}$	n_g	n_h
SCHOTT N-BK7®* 517642.251	1.51680	64.17	0.008054	1.51872	63.96	0.008110	1.51289	1.51432	1.52283	1.52668	1.53024
N-BK7HT* 517642.251	1.51680	64.17	0.008054	1.51872	63.96	0.008110	1.51289	1.51432	1.52283	1.52668	1.53024
N-BK10 498670.239	1.49782	66.95	0.007435	1.49960	66.78	0.007481	1.49419	1.49552	1.50337	1.50690	1.51014
N-K5 522595.259	1.52249	59.48	0.008784	1.52458	59.22	0.008858	1.51829	1.51982	1.52910	1.53338	1.53734
K7 511604.253	1.51112	60.41	0.008461	1.51314	60.15	0.008531	1.50707	1.50854	1.51748	1.52159	1.52540
K10 501564.252	1.50137	56.41	0.008888	1.50349	56.15	0.008967	1.49713	1.49867	1.50807	1.51243	1.51649
N-ZK7 508612.249	1.50847	61.19	0.008310	1.51045	60.98	0.008370	1.50445	1.50592	1.51470	1.51869	1.52238

*** Available in step 0.5**

$P_{g,F}$	$\Delta P_{g,F}$	CR	FR	SR	AR	PR	α (–30/+70)	T_g	$T_{10^{7.6}}$	ρ	HK	HG	τ_i (10/400)	FC
0.5349	–0.0009	1	0	1	2.3	2.3	7.1	557	719	2.51	610	3	0.997	33/29
0.5349	–0.0009	1	0	1	2.3	2.3	7.1	557	719	2.51	610	3	0.998	33/29
0.5303	–0.0008	1	0	1	1	1	5.8	551	753	2.39	560	4	0.996	31/27
0.5438	0.0000	1	0	1	1	1	8.2	546	720	2.59	530	3	0.995	34/30
0.5422	0.0000	3	0	2	1	2.3	8.4	513	712	2.53	520	3	0.996	33/30
0.5475	–0.0015	1	0	1	1	1.2	6.5	459	691	2.52	470	4	0.994	33/30
0.5370	–0.0039	1	0	2	1.2	2.2	4.5	539	721	2.49	530	4	0.990	34/29

Glass type	n_d	ν_d	$n_F - n_C$	n_e	ν_e	$n_{F'} - n_{C'}$	n_r	n_C	$n_{F'}$	n_g	n_h
N-BAK1 573576.319	1.57250	57.55	0.009948	1.57487	57.27	0.010039	1.56778	1.56949	1.58000	1.58488	1.58941
N-BAK2 540597.286	1.53996	59.71	0.009043	1.54212	59.44	0.009120	1.53564	1.53721	1.54677	1.55117	1.55525
N-BAK4 569560.305	1.56883	55.98	0.010162	1.57125	55.70	0.010255	1.56400	1.56575	1.57649	1.58149	1.58614
N-BAK4HT 569560.305	1.56883	55.98	0.010162	1.57125	55.70	0.010255	1.56400	1.56575	1.57649	1.58149	1.58614
N-SK2* 607567.355	1.60738	56.65	0.010722	1.60994	56.37	0.010821	1.60230	1.60414	1.61547	1.62073	1.62562
N-SK2HT 607567.355	1.60738	56.65	0.010722	1.60994	56.37	0.010821	1.60230	1.60414	1.61547	1.62073	1.62562
N-SK4 613586.354	1.61272	58.63	0.010450	1.61521	58.37	0.010541	1.60774	1.60954	1.62059	1.62568	1.63042
N-SK5 589613.330	1.58913	61.27	0.009616	1.59142	61.02	0.009692	1.58451	1.58619	1.59635	1.60100	1.60530
N-SK11 564608.308	1.56384	60.80	0.009274	1.56605	60.55	0.009349	1.55939	1.56101	1.57081	1.57530	1.57946
N-SK14 603606.344	1.60311	60.60	0.009953	1.60548	60.34	0.010034	1.59834	1.60008	1.61059	1.61542	1.61988

*** Available in step 0.5**

$P_{g,F}$	$\Delta P_{g,F}$	CR	FR	SR	AR	PR	α (–30/+70)	T_g	$T_{10}^{7.6}$	ρ	HK	HG	τ_i (10/400)	FC
0.5472	0.0002	2	1	3.3	1.2	2	7.6	592	746	3.19	530	2	0.996	33/29
0.5437	0.0004	2	0	1	1	2.3	8.0	554	727	2.86	530	2	0.997	32/28
0.5487	–0.0010	1	0	1.2	1	1	7.0	581	725	3.05	550	2	0.992	36/33
0.5487	–0.0010	1	0	1.2	1	1	7.0	581	725	3.05	550	2	0.993	36/33
0.5477	–0.0008	2	0	2.2	1	2.3	6.0	659	823	3.55	550	2	0.994	35/30
0.5477	–0.0008	2	0	2.2	1	2.3	6.0	659	823	3.55	550	2	0.996	34/30
0.5448	–0.0004	3	1	51.2	2	2	6.5	658	769	3.54	580	3	0.990	36/32
0.5400	–0.0007	3	1	4.4	2	1.3	5.5	660	791	3.30	590	3	0.992	34/29
0.5411	–0.0004	2	0	2	1	2.3	6.5	610	760	3.08	570	2	0.990	34/29
0.5415	–0.0003	4	2	51.3	2	2.3	6.0	649	773	3.44	600	3	0.990	35/29

BAK
SK

Glass type	n_d	ν_d	$n_F - n_C$	n_e	ν_e	$n_{F'} - n_{C'}$	n_r	n_C	$n_{F'}$	n_g	n_h
N-SK16 620603.358	1.62041	60.32	0.010285	1.62286	60.08	0.010368	1.61548	1.61727	1.62814	1.63312	1.63773

$P_{g,F}$	$\Delta P_{g,F}$	CR	FR	SR	AR	PR	α (–30/+70)	T_g	$T_{10^{7.6}}$	ρ	HK	HG	τ_i (10/400)	FC
0.5412	−0.0011	4	4	53.3	3.3	3.2	6.3	636	750	3.58	600	4	0.988	36/30

Glass type	n_d	ν_d	$n_F - n_C$	n_e	ν_e	$n_{F'} - n_{C'}$	n_r	n_C	$n_{F'}$	n_g	n_h
N-KF9 523515.250	1.52346	51.54	0.010156	1.52588	51.26	0.010258	1.51867	1.52040	1.53114	1.53620	1.54096
N-BALF4 580539.311	1.57956	53.87	0.010759	1.58212	53.59	0.010863	1.57447	1.57631	1.58769	1.59301	1.59799
N-BALF5 547536.261	1.54739	53.63	0.010207	1.54982	53.36	0.010303	1.54255	1.54430	1.55510	1.56016	1.56491
N-SSK2 622533.353	1.62229	53.27	0.011681	1.62508	52.99	0.011795	1.61678	1.61877	1.63112	1.63691	1.64232
N-SSK5 658509.371	1.65844	50.88	0.012940	1.66152	50.59	0.013075	1.65237	1.65455	1.66824	1.67471	1.68079
N-SSK8 618498.327	1.61773	49.83	0.012397	1.62068	49.54	0.012529	1.61192	1.61401	1.62713	1.63335	1.63923
N-LAK7 652585.384	1.65160	58.52	0.011135	1.65425	58.26	0.011229	1.64628	1.64821	1.65998	1.66539	1.67042
N-LAK8 713538.375	1.71300	53.83	0.013245	1.71616	53.61	0.013359	1.70668	1.70897	1.72297	1.72944	1.73545

$P_{g,F}$	$\Delta P_{g,F}$	CR	FR	SR	AR	PR	α (–30/+70)	T_g	$T_{10^{7.6}}$	ρ	HK	HG	τ_i (10/400)	FC
0.5558	−0.0014	1	0	1	1	1	9.6	476	640	2.50	480	1	0.986	37/34
0.5520	−0.0012	1	0	1	1	1	6.5	578	661	3.11	540	2	0.985	37/33
0.5532	−0.0004	1	0	1	2	1	7.3	558	711	2.61	600	2	0.983	37/34
0.5526	−0.0016	1	0	1.2	1	1	5.8	653	801	3.53	570	3	0.981	37/33
0.5575	−0.0007	2	3	52.2	2.2	3.2	6.8	645	751	3.71	590	5	0.959	38/34
0.5602	0.0002	1	0	1	1.3	1	7.2	616	742	3.27	570	3	0.950	39/35
0.5433	−0.0021	3	2	53.3	3.3	4.3	7.1	618	716	3.84	600	5	0.988	35/29
0.5450	−0.0083	3	2	52.3	1	3.3	5.6	643	717	3.75	740	2	0.977	37/30

KF
BALF
SSK
LAK

Glass type	n_d	ν_d	$n_F - n_C$	n_e	ν_e	$n_{F'} - n_{C'}$	n_r	n_C	$n_{F'}$	n_g	n_h
N-LAK9* 691547.351	1.69100	54.71	0.012631	1.69401	54.48	0.012738	1.68497	1.68716	1.70051	1.70667	1.71239
N-LAK10 720506.369	1.72003	50.62	0.014224	1.72341	50.39	0.014357	1.71328	1.71572	1.73077	1.73779	1.74438
N-LAK12 678552.410	1.67790	55.20	0.012281	1.68083	54.92	0.012396	1.67209	1.67419	1.68717	1.69320	1.69882
N-LAK14 697554.363	1.69680	55.41	0.012575	1.69980	55.19	0.012679	1.69077	1.69297	1.70626	1.71237	1.71804
N-LAK21 640601.374	1.64049	60.10	0.010657	1.64304	59.86	0.010743	1.63538	1.63724	1.64850	1.65366	1.65844
N-LAK22 651559.377	1.65113	55.89	0.011650	1.65391	55.63	0.011755	1.64560	1.64760	1.65992	1.66562	1.67092
N-LAK33B 755523.422	1.75500	52.30	0.014436	1.75844	52.07	0.014566	1.74814	1.75062	1.76589	1.77296	1.77954
N-LAK34 729545.402	1.72916	54.50	0.013379	1.73235	54.27	0.013493	1.72277	1.72509	1.73923	1.74575	1.75180

*** Available in step 0.5**

$P_{g,F}$	$\Delta P_{g,F}$	CR	FR	SR	AR	PR	α (–30/+70)	T_g	$T_{10^{7.6}}$	ρ	HK	HG	τ_i (10/400)	FC
0.5447	–0.0071	3	3	52	1.2	4.3	6.3	656	722	3.51	700	3	0.980	37/31
0.5515	–0.0072	2	2	52.3	1	3	5.7	636	714	3.69	780	2	0.959	39/34
0.5485	–0.0024	3	1	53.3	3.3	4.3	7.6	614	714	4.10	560	6	0.976	37/31
0.5427	–0.0079	3	2	52.3	1	3	5.5	661	734	3.63	730	2	0.981	37/30
0.5411	–0.0017	4	2	53.2	4.3	4.3	6.8	639	716	3.74	600	5	0.979	37/31
0.5467	–0.0031	2	2	51.2	1	2.3	6.6	689		3.77	600	4	0.985	36/30
0.5473	–0.0085	1	1	51.3	1	2	5.8	668	750	4.22	797		0.980	37/28
0.5443	–0.0079	1	0	52.3	1	3.3	5.8	668	740	4.02	740	2	0.981	37/28

Glass type	n_d	ν_d	$n_F - n_C$	n_e	ν_e	$n_{F'} - n_{C'}$	n_r	n_C	$n_{F'}$	n_g	n_h
LLF1 548458.294	1.54814	45.75	0.011981	1.55099	45.47	0.012118	1.54256	1.54457	1.55725	1.56333	1.56911
N-BAF4 606437.289	1.60568	43.72	0.013853	1.60897	43.43	0.014021	1.59926	1.60157	1.61624	1.62336	1.63022
N-BAF10 670471.375	1.67003	47.11	0.014222	1.67341	46.83	0.014380	1.66339	1.66578	1.68083	1.68801	1.69480
N-BAF51 652450.333	1.65224	44.96	0.014507	1.65569	44.67	0.014677	1.64551	1.64792	1.66328	1.67065	1.67766
N-BAF52 609466.305	1.60863	46.60	0.013061	1.61173	46.30	0.013211	1.60254	1.60473	1.61856	1.62521	1.63157

$P_{g,F}$	$\Delta P_{g,F}$	CR	FR	SR	AR	PR	α (–30/+70)	T_g	$T_{10^{7.6}}$	ρ	HK	HG	τ_i (10/400)	FC
0.5660	–0.0009	1	0	1	2	1	8.1	431	628	2.94	450	3	0.997	33/31
0.5733	0.0030	1	0	1	1.2	1.3	7.2	580	709	2.89	610	3	0.946	39/35
0.5629	–0.0016	1	0	4.3	1.3	1	6.2	660	790	3.75	620	4	0.950	39/35
0.5670	–0.0012	2	0	5.4	1.3	1	8.4	569	712	3.33	560	5	0.954	39/34
0.5678	0.0024	1	0	1	1.3	1	6.9	594	716	3.05	600	3	0.950	39/35

LLF
BAF

Glass type	n_d	ν_d	$n_F - n_C$	n_e	ν_e	$n_{F'} - n_{C'}$	n_r	n_C	$n_{F'}$	n_g	n_h
LF5 581409.322	1.58144	40.85	0.014233	1.58482	40.57	0.014413	1.57489	1.57723	1.59231	1.59964	1.60668
N-F2 620364.265	1.62005	36.43	0.017020	1.62408	36.16	0.017258	1.61229	1.61506	1.63310	1.64209	1.65087
F2 620364.360	1.62004	36.37	0.017050	1.62408	36.11	0.017284	1.61227	1.61503	1.63310	1.64202	1.65064
F2HT 620364.360	1.62004	36.37	0.017050	1.62408	36.11	0.017284	1.61227	1.61503	1.63310	1.64202	1.65064
F5 603380.347	1.60342	38.03	0.015867	1.60718	37.77	0.016078	1.59616	1.59875	1.61556	1.62381	1.63176
N-BASF2 664360.315	1.66446	36.00	0.018457	1.66883	35.73	0.018720	1.65607	1.65905	1.67862	1.68838	1.69792
N-BASF64 704394.320	1.70400	39.38	0.017875	1.70824	39.12	0.018105	1.69578	1.69872	1.71765	1.72690	1.73581

$P_{g,F}$	$\Delta P_{g,F}$	CR	FR	SR	AR	PR	α (–30/+70)	T_g	$T_{10^{7.6}}$	ρ	HK	HG	τ_i (10/400)	FC
0.5748	–0.0003	2	0	1	2.3	2	9.1	419	585	3.22	450	2	0.997	34/31
0.5881	0.0056	1	0	1	1	1	7.8	569	686	2.65	600	2	0.946	39/36
0.5828	0.0002	1	0	1	2.3	1.3	8.2	434	594	3.60	420	2	0.994	35/32
0.5828	0.0002	1	0	1	2.3	1.3	8.2	434	594	3.60	420	2	0.996	35/32
0.5795	–0.0003	1	0	1	2.3	2	8.0	438	608	3.47	450	3	0.993	35/32
0.5890	0.0057	1	0	1	1	1	7.1	619	766	3.15	580	3	0.891	41/36
0.5769	–0.0006	1	0	3.2	1.2	1	7.3	582	712	3.20	650	4	0.924	40/35

Glass type	n_d	ν_d	$n_F - n_C$	n_e	ν_e	$n_{F'} - n_{C'}$	n_r	n_C	$n_{F'}$	n_g	n_h
N-LAF2 744449.430	1.74397	44.85	0.016588	1.74791	44.57	0.016780	1.73627	1.73903	1.75659	1.76500	1.77298
N-LAF7 750348.373	1.74950	34.82	0.021525	1.75459	34.56	0.021833	1.73972	1.74320	1.76602	1.77741	1.78854
LAFN7 750350.438	1.74950	34.95	0.021445	1.75458	34.72	0.021735	1.73970	1.74319	1.76592	1.77713	1.78798
N-LAF21 788475.428	1.78800	47.49	0.016593	1.79195	47.25	0.016761	1.78019	1.78301	1.80056	1.80882	1.81657
N-LAF33 786441.436	1.78582	44.05	0.017839	1.79007	43.80	0.018038	1.77751	1.78049	1.79937	1.80837	1.81687
N-LAF34 773496.424	1.77250	49.62	0.015568	1.77621	49.38	0.015719	1.76515	1.76780	1.78427	1.79196	1.79915
N-LAF35 743494.412	1.74330	49.40	0.015047	1.74688	49.16	0.015194	1.73620	1.73876	1.75467	1.76212	1.76908

$P_{g,F}$	$\Delta P_{g,F}$	CR	FR	SR	AR	PR	α (–30/+70)	T_g	$T_{10}^{7.6}$	ρ	HK	HG	τ_i (10/400)	FC
0.5656	–0.0027	2	3	52.2	1	2.2	8.1	653	742	4.30	530	6	0.933	40/34
0.5894	0.0042	1	2	51.3	1.2	1.2	7.3	568	669	3.73	530	5	0.752	46/36
0.5825	–0.0025	3	1	53.3	2.2	4.3	5.3	500	573	4.38	520	3	0.937	40/35
0.5555	–0.0084	1	1	51.3	1	1.3	6.0	653	729	4.28	730	2	0.966	39/32
0.5626	–0.0071	1	2	52.2	1	3	5.6	600	673	4.36	730	1	0.963	39/32
0.5518	–0.0085	1	1	51.3	1	1	5.8	668	745	4.24	770	2	0.980	38/30
0.5523	–0.0084	2	1	52.3	1	3.3	5.3	589	669	4.12	660	2	0.976	38/30

Glass type	n_d	ν_d	$n_F - n_C$	n_e	ν_e	$n_{F'} - n_{C'}$	n_r	n_C	$n_{F'}$	n_g	n_h
N-LASF9 850322.441	1.85025	32.17	0.026430	1.85650	31.93	0.026827	1.83834	1.84255	1.87058	1.88467	1.89845
N-LASF9HT 850322.441	1.85025	32.17	0.026430	1.85650	31.93	0.026827	1.83834	1.84255	1.87058	1.88467	1.89845
N-LASF31A 883408.551	1.88300	40.76	0.021663	1.88815	40.52	0.021921	1.87298	1.87656	1.89950	1.91050	1.92093
LASF35 022291.541	2.02204	29.06	0.035170	2.03035	28.84	0.035721	2.00628	2.01185	2.04916	2.06805	2.08663
N-LASF40 834373.443	1.83404	37.30	0.022363	1.83935	37.04	0.022658	1.82380	1.82745	1.85114	1.86275	1.87393
N-LASF41 835431.485	1.83501	43.13	0.019361	1.83961	42.88	0.019578	1.82599	1.82923	1.84972	1.85949	1.86872
N-LASF43 806406.426	1.80610	40.61	0.019850	1.81081	40.36	0.020089	1.79691	1.80020	1.82122	1.83137	1.84106
N-LASF44* 804465.444	1.80420	46.50	0.017294	1.80832	46.25	0.017476	1.79609	1.79901	1.81731	1.82594	1.83405
N-LASF45 801350.363	1.80107	34.97	0.022905	1.80650	34.72	0.023227	1.79066	1.79436	1.81864	1.83068	1.84237
N-LASF45HT 801350.363	1.80107	34.97	0.022905	1.80650	34.72	0.023227	1.79066	1.79436	1.81864	1.83068	1.84237
N-LASF46A 904313.445	1.90366	31.32	0.028853	1.91048	31.09	0.029287	1.89064	1.89526	1.92586	1.94129	1.95645

*** Available in step 0.5**

$P_{g,F}$	$\Delta P_{g,F}$	CR	FR	SR	AR	PR	α (–30/+70)	T_g	$T_{10}^{7.6}$	ρ	HK	HG	τ_i (10/400)	FC
0.5934	0.0037	1	0	2	1	1	7.4	683	817	4.41	515	4	0.799	41/36*
0.5934	0.0037	1	0	2	1	1	7.4	683	817	4.41	515	4	0.843	40/36*
0.5667	–0.0085	1	0	2.3	1	1	6.7	719	830	5.51	650	2	0.933	38/33*
0.5982	0.0033	1	0	1.3	1	1.3	7.4	774		5.41	810	1	0.634	45/37*
0.5786	–0.0024	1	1	51.2	1	1.3	5.8	590	677	4.43	580	1	0.891	39/35*
0.5629	–0.0083	1	1	4	1	1	6.2	651	739	4.85	760	2	0.948	37/32*
0.5703	–0.0052	1	1	51.3	1	2	5.5	614	699	4.26	720	2	0.919	42/34
0.5572	–0.0084	1	1	4	1	1	6.2	655	742	4.44	770	2	0.963	40/31
0.5859	0.0009	1	0	3.2	1	1	7.4	647	773	3.63	630	3	0.857	44/35
0.5859	0.0009	1	0	3.2	1	1	7.4	647	773	3.63	630	3	0.886	43/35
0.5953	0.0042	1	0	3	1	1	6.0	638	733	4.45	666	1	0.815	41/37*

* Wavelength for transmittance 0.7 and 0.05

Glass type	n_d	ν_d	$n_F - n_C$	n_e	ν_e	$n_{F'} - n_{C'}$	n_r	n_C	$n_{F'}$	n_g	n_h
N-LASF46B 904313.451	1.90366	31.32	0.028852	1.91048	31.09	0.029289	1.89065	1.89526	1.92586	1.94130	1.95647

$P_{g,F}$	$\Delta P_{g,F}$	CR	FR	SR	AR	PR	α (–30/+70)	T_g	$T_{10}^{7.6}$	ρ	HK	HG	τ_i (10/400)	FC
0.5956	0.0045	1	0	3.3	1	1	6.0	611	703	4.51	712		0.847	40/36*

* Wavelength for transmittance 0.7 and 0.05

Glass type	n_d	ν_d	$n_F - n_C$	n_e	ν_e	$n_{F'} - n_{C'}$	n_r	n_C	$n_{F'}$	n_g	n_h
N-SF1 717296.303	1.71736	29.62	0.024219	1.72308	29.39	0.024606	1.70651	1.71035	1.73605	1.74919	1.76224
N-SF2 648338.272	1.64769	33.82	0.019151	1.65222	33.56	0.019435	1.63902	1.64210	1.66241	1.67265	1.68273
N-SF4 755274.315	1.75513	27.38	0.027583	1.76164	27.16	0.028044	1.74286	1.74719	1.77647	1.79158	1.80668
N-SF5* 673323.286	1.67271	32.25	0.020858	1.67763	32.00	0.021177	1.66330	1.66664	1.68876	1.69998	1.71106
N-SF6 805254.337	1.80518	25.36	0.031750	1.81266	25.16	0.032304	1.79114	1.79608	1.82980	1.84738	1.86506
N-SF6HT 805254.337	1.80518	25.36	0.031750	1.81266	25.16	0.032304	1.79114	1.79608	1.82980	1.84738	1.86506
N-SF6HTultra 805254.337	1.80518	25.36	0.031750	1.81266	25.16	0.032304	1.79114	1.79608	1.82980	1.84738	1.86506
N-SF8 689313.290	1.68894	31.31	0.022005	1.69413	31.06	0.022346	1.67904	1.68254	1.70589	1.71775	1.72948
N-SF10 728285.305	1.72828	28.53	0.025524	1.73430	28.31	0.025941	1.71688	1.72091	1.74800	1.76191	1.77578
N-SF11 785257.322	1.78472	25.68	0.030558	1.79192	25.47	0.031088	1.77119	1.77596	1.80841	1.82533	1.84235
N-SF14 762265.312	1.76182	26.53	0.028715	1.76859	26.32	0.029204	1.74907	1.75356	1.78405	1.79986	1.81570

*** Available in step 0.5**

$P_{g,F}$	$\Delta P_{g,F}$	CR	FR	SR	AR	PR	α (–30/+70)	T_g	$T_{10^{7.6}}$	ρ	HK	HG	τ_i (10/400)	FC
0.6037	0.0097	1	0	1	1	1	9.1	553	660	3.03	540	5	0.867	41/36
0.5950	0.0081	1	0	1	1.2	1	6.7	608	731	2.72	539		0.928	40/36
0.6096	0.0118	1	0	1.3	1	1	9.5	570	661	3.15	520	6	0.830	43/36
0.5984	0.0088	1	0	1	1	1	7.9	578	693	2.86	620	3	0.905	40/36
0.6158	0.0146	1	0	2	1	1	9.0	589	683	3.37	550	4	0.821	44/37
0.6158	0.0146	1	0	2	1	1	9.0	589	683	3.37	550	4	0.877	44/37
0.6158	0.0146	1	0	2	1	1	9.0	589	683	3.37	550	4	0.887	43/37
0.5999	0.0087	1	0	1	1	1	8.6	567	678	2.90	600	4	0.901	41/36
0.6066	0.0108	1	0	1	1	1	9.4	559	652	3.05	540	5	0.837	42/36
0.6156	0.0150	1	0	1	1	1	8.5	592	688	3.22	615	4	0.815	44/37
0.6122	0.0130	1	0	1	1	1	9.4	566	657	3.12	515	5	0.891	42/36

SF

Glass type	n_d	ν_d	$n_F - n_C$	n_e	ν_e	$n_{F'} - n_{C'}$	n_r	n_C	$n_{F'}$	n_g	n_h
N-SF15 699302.292	1.69892	30.20	0.023142	1.70438	29.96	0.023511	1.68854	1.69222	1.71677	1.72933	1.74182
N-SF57 847238.353	1.84666	23.78	0.035604	1.85504	23.59	0.036247	1.83099	1.83650	1.87432	1.89423	1.91440
N-SF57HT 847238.353	1.84666	23.78	0.035604	1.85504	23.59	0.036247	1.83099	1.83650	1.87432	1.89423	1.91440
N-SF57HTultra 847238.353	1.84666	23.78	0.035604	1.85504	23.59	0.036247	1.83099	1.83650	1.87432	1.89423	1.91440
N-SF66 923209.400	1.92286	20.88	0.044199	1.93322	20.70	0.045076	1.90368	1.91039	1.95739	1.98285	
SF1 717295.446	1.71736	29.51	0.024307	1.72310	29.29	0.024687	1.70647	1.71031	1.73610	1.74916	1.76201
SF2* 648339.386	1.64769	33.85	0.019135	1.65222	33.60	0.019412	1.63902	1.64210	1.66238	1.67249	1.68233
SF4 755276.479	1.75520	27.58	0.027383	1.76167	27.37	0.027829	1.74300	1.74730	1.77636	1.79121	1.80589
SF5 673322.407	1.67270	32.21	0.020885	1.67764	31.97	0.021195	1.66327	1.66661	1.68876	1.69986	1.71069
SF6 805254.518	1.80518	25.43	0.031660	1.81265	25.24	0.032201	1.79117	1.79609	1.82970	1.84707	1.86436
SF6HT 805254.518	1.80518	25.43	0.031660	1.81265	25.24	0.032201	1.79117	1.79609	1.82970	1.84707	1.86436

*** Available in step 0.5**

$P_{g,F}$	$\Delta P_{g,F}$	CR	FR	SR	AR	PR	α (–30/+70)	T_g	$T_{10^{7.6}}$	ρ	HK	HG	τ_i (10/400)	FC
0.6038	0.0108	1	0	1	1	1	8.0	580	692	2.92	610	3	0.857	42/37
0.6216	0.0178	1	0	1	1	1	8.5	629	716	3.53	520	4	0.733	42/37*
0.6216	0.0178	1	0	1	1	1	8.5	629	716	3.53	520	4	0.793	41/37*
0.6216	0.0178	1	0	1	1	1	8.5	629	716	3.53	520	4	0.830	40/37*
0.6394	0.0307	1	0	1	1	1	5.9	710	806	4.00	440	3	0.504	45/39*
0.5983	0.0042	2	1	3.2	2.3	3	8.1	417	566	4.46	390	1	0.967	39/34
0.5886	0.0017	1	0	2	2.3	2	8.4	441	600	3.86	410	2	0.981	37/33
0.6036	0.0062	1	2	4.3	2.3	3.3	8.0	420	552	4.79	390	1	0.954	40/35
0.5919	0.0023	1	1	2	2.3	3	8.2	425	580	4.07	410	2	0.980	37/33
0.6102	0.0092	2	3	51.3	2.3	3.3	8.1	423	538	5.18	370	1	0.915	42/36
0.6102	0.0092	2	3	51.3	2.3	3.3	8.1	423	538	5.18	370	1	0.941	41/36

* Wavelength for transmittance 0.7 and 0.05

Glass type	n_d	ν_d	$n_F - n_C$	n_e	ν_e	$n_{F'} - n_{C'}$	n_r	n_C	$n_{F'}$	n_g	n_h
SF10 728284.428	1.72825	28.41	0.025633	1.73430	28.19	0.026051	1.71681	1.72085	1.74805	1.76198	1.77579
SF11 785258.474	1.78472	25.76	0.030467	1.79190	25.55	0.030997	1.77125	1.77599	1.80834	1.82518	1.84208
SF56A 785261.492	1.78470	26.08	0.030092	1.79180	25.87	0.030603	1.77136	1.77605	1.80800	1.82449	1.84092
SF57 847238.551	1.84666	23.83	0.035536	1.85504	23.64	0.036166	1.83102	1.83650	1.87425	1.89393	1.91366
SF57HTultra* 847238.551	1.84666	23.83	0.035536	1.85504	23.64	0.036166	1.83102	1.83650	1.87425	1.89393	1.91366

*** Available in step 0.5**

$P_{g,F}$	$\Delta P_{g,F}$	CR	FR	SR	AR	PR	α (–30/+70)	T_g	$T_{10}^{7.6}$	ρ	HK	HG	τ_i (10/400)	FC
0.6046	0.0085	1	0	1	1.2	2	7.5	454	595	4.28	430	1	0.862	41/37
0.6147	0.0142	1	0	1	1.2	1	6.1	503	635	4.74	450	1	0.525	44/39
0.6098	0.0098	1	1	3.2	2.2	3.2	7.9	429	556	4.92	380	1	0.857	42/37
0.6160	0.0123	2	5	52.3	2.3	4.3	8.3	414	519	5.51	350	1	0.847	40/37*
0.6160	0.0123	2	5	52.3	2.3	4.3	8.3	414	519	5.51	350	1	0.924	39/36*

* Wavelength for transmittance 0.7 and 0.05

Glass type	n_d	ν_d	$n_F - n_C$	n_e	ν_e	$n_{F'} - n_{C'}$	n_r	n_C	$n_{F'}$	n_g	n_h
N-KZFS2* 558540.255	1.55836	54.01	0.010338	1.56082	53.83	0.010418	1.55337	1.55519	1.56612	1.57114	1.57580
N-KZFS4* 613445.300	1.61336	44.49	0.013785	1.61664	44.27	0.013929	1.60688	1.60922	1.62380	1.63071	1.63723
N-KZFS4HT* 613445.300	1.61336	44.49	0.013785	1.61664	44.27	0.013929	1.60688	1.60922	1.62380	1.63071	1.63723
N-KZFS5* 654397.304	1.65412	39.70	0.016477	1.65803	39.46	0.016675	1.64649	1.64922	1.66667	1.67511	1.68318
N-KZFS8* 720347.320	1.72047	34.70	0.020763	1.72539	34.47	0.021046	1.71099	1.71437	1.73637	1.74724	1.75777
N-KZFS11* 638424.320	1.63775	42.41	0.015038	1.64132	42.20	0.015198	1.63069	1.63324	1.64915	1.65670	1.66385

*** Available in step 0.5**

$P_{g,F}$	$\Delta P_{g,F}$	CR	FR	SR	AR	PR	α (−30/+70)	T_g	$T_{10}{}^{7.6}$	ρ	HK	HG	τ_i (10/400)	FC
0.5419	−0.0111	1	4	52.3	4.3	4.2	4.4	491	600	2.54	490	3	0.985	34/30
0.5590	−0.0100	1	1	3.4	1.2	1	7.3	536	664	3.00	520	3	0.979	36/32
0.5590	−0.0100	1	1	3.4	1.2	1	7.3	536	664	3.00	520	3	0.985	36/32
0.5710	−0.0060	1	0	1	1	1	6.4	584	739	3.04	555		0.976	37/32
0.5833	−0.0021	1	0	1	1	1	7.8	509	635	3.20	570	4	0.963	38/33
0.5605	−0.0120	1	1	3.4	1	1	6.6	551		3.20	530	3	0.987	36/30

Glass type	n_d	ν_d	$n_F - n_C$	n_e	ν_e	$n_{F'} - n_{C'}$	n_r	n_C	$n_{F'}$	n_g	n_h
P-BK7 516641.243	1.51640	64.06	0.008061	1.51832	63.87	0.008115	1.51248	1.51392	1.52243	1.52628	1.52982
P-SK57Q1 586595.301	1.58600	59.50	0.009849	1.58835	59.26	0.009928	1.58127	1.58299	1.59340	1.59817	1.60260
P-SK57 587596.301	1.58700	59.60	0.009849	1.58935	59.36	0.009928	1.58227	1.58399	1.59440	1.59917	1.60359
P-SK58A 589612.297	1.58913	61.15	0.009634	1.59143	60.93	0.009707	1.58449	1.58618	1.59636	1.60100	1.60530
P-SK60 610579.308	1.61035	57.90	0.010541	1.61286	57.66	0.010628	1.60530	1.60714	1.61828	1.62340	1.62815
P-SF8 689313.290	1.68893	31.25	0.022046	1.69414	31.01	0.022386	1.67901	1.68252	1.70591	1.71778	1.72950
P-LAK35 693532.385	1.69350	53.20	0.013036	1.69661	52.95	0.013156	1.68732	1.68955	1.70334	1.70974	1.71569
P-SF69 723292.293	1.72250	29.23	0.024718	1.72883	29.00	0.025116	1.71144	1.71535	1.74158	1.75502	1.76840
P-LAF37 755457.399	1.75550	45.66	0.016546	1.75944	45.42	0.016722	1.74775	1.75054	1.76804	1.77633	1.78414
P-LASF47 806409.454	1.80610	40.90	0.019709	1.81078	40.66	0.019941	1.79696	1.80023	1.82110	1.83112	1.84064
P-LASF50 809405.454	1.80860	40.46	0.019985	1.81335	40.22	0.020223	1.79934	1.80266	1.82382	1.83399	1.84367

$P_{g,F}$	$\Delta P_{g,F}$	n_d ref.[*1]	After Molding[*2]		SR-J	WR-J	α (–30/+70)	α (20/300)	T_g	AT	ρ	HK	Abrasion Aa	τ_i (10/400)	FC
			n_d	ν_d											
0.5335	–0.0025	1.51576	1.5144	63.9	1	4	6.0	7.3	498	546	2.43	627	66	0.997	33/30
0.5414	–0.0024	1.58496	1.5833	59.4	4	1	7.2	8.9	493	522	3.01	535	124	0.994	34/31
0.5412	–0.0024	1.58596	1.5843	59.4	4	1	7.2	8.9	493	522	3.01	535	124	0.994	34/31
0.5386	–0.0023	1.58795	1.5860	60.8	4	2	6.8	8.4	510	551	2.97	662	102	0.994	35/31
0.5427	–0.0037	1.60918	1.6068	57.7	4	3	7.1	8.9	507	547	3.08	601	86	0.997	33/29
0.5991	0.0079	1.68623	1.6814	31.7	1	1	9.4	11.1	524	580	2.90	533	200	0.924	40/36
0.5482	–0.0061	1.69234	1.6904	53.0	4	3	8.1	9.7	508	544	3.85	616	119	0.988	36/29
0.6050	0.0104	1.72006	1.7155	29.7	1	1	9.0	11.1	508	547	2.93	612	142	0.915	41/36
0.5590	–0.0080	1.75396	1.7508	45.5	4	1	6.3	7.8	506	546	3.99	697	67	0.980	37/31
0.5671	–0.0079	1.80449	1.8016	40.8	3	1	6.0	7.3	530	580	4.54	620	70	0.967	39/33
0.5680	–0.0078	1.80699	1.8036	40.3			5.9	7.3	527	571	4.54	655	62	0.967	39/32

[*1] n_d reference value (annealing rate 25 K/h)

[*2] as pressed at SCHOTT; for details, please consult SCHOTT

Glass type	n_d	ν_d	$n_F - n_C$	n_e	ν_e	$n_{F'} - n_{C'}$	n_r	n_C	$n_{F'}$	n_g	n_h
P-LASF51 810409.458	1.81000	40.93	0.019792	1.81470	40.68	0.020025	1.80082	1.80411	1.82506	1.83512	1.84467
P-SF68 005210.619	2.00520	21.00	0.047867	2.01643	20.82	0.048826	1.98449	1.99171	2.04262	2.07018	
N-FK51A 487845.368	1.48656	84.47	0.005760	1.48794	84.07	0.005804	1.48379	1.48480	1.49088	1.49364	1.49618
N-FK5 487704.245	1.48749	70.41	0.006924	1.48914	70.23	0.006965	1.48410	1.48535	1.49266	1.49593	1.49894
N-PK52A 497816.370	1.49700	81.61	0.006090	1.49845	81.21	0.006138	1.49408	1.49514	1.50157	1.50450	1.50720
N-PK51 529770.386	1.52855	76.98	0.006867	1.53019	76.58	0.006923	1.52527	1.52646	1.53372	1.53704	1.54010
N-KZFS2 558540.255	1.55836	54.01	0.010338	1.56082	53.83	0.010418	1.55337	1.55519	1.56612	1.57114	1.57580
N-KZFS4 613445.300	1.61336	44.49	0.013785	1.61664	44.27	0.013929	1.60688	1.60922	1.62380	1.63071	1.63723

$P_{g,F}$	$\Delta P_{g,F}$	n_d ref.*1	After Molding*2		SR-J	WR-J	α (–30/+70)	α (20/300)	T_g	AT	ρ	HK	Abrasion Aa	τ_i (10/400)	FC
			n_d	ν_d											
0.5670	–0.0080	1.80842	1.8055	40.8	3	1	6.0	7.4	526	570	4.58	722	66	0.967	39/33
0.6392	0.0308	2.00365	1.9958	20.9	4	1	8.4	9.7	428	468	6.19	404	298	0.007	49/41*
0.5359	0.0342	1.48597	1.4847	84.2	3	1	12.7	14.8	464	503	3.68	345	528	0.997	34/28
0.5290	0.0036	1.48666	1.485	70.2	5	4	9.2	10.0	466	557	2.45	520	109	0.998	30/27
0.5377	0.0311	1.49640	1.4952	81.3	4	1	13.0	15.0	467	520	3.70	355	526	0.997	34/28
0.5401	0.0258	1.52784	1.5267	76.7	3	1	12.4	14.1	487	528	3.86	415	592	0.994	34/29
0.5419	–0.0111	1.55666	1.5534	53.7	6	6	4.4	5.4	472	533	2.54	490	70	0.985	34/30
0.5590	–0.0100	1.61227	1.6100	44.5	6	4	7.3	8.2	536	597	3.00	520	130	0.979	36/32

*1 n_d reference value (annealing rate 25 K/h) *2 as pressed at SCHOTT; for details, please consult SCHOTT

* Wavelength for transmittance 0.7 and 0.05

Glass type	n_d	ν_d	$n_F - n_C$	n_e	ν_e	$n_{F'} - n_{C'}$	n_r	n_C	$n_{F'}$	n_g	n_h
N-KZFS4HT 613445.300	1.61336	44.49	0.013785	1.61664	44.27	0.013929	1.60688	1.60922	1.62380	1.63071	1.63723
N-KZFS11 638424.320	1.63775	42.41	0.015038	1.64132	42.20	0.015198	1.63069	1.63324	1.64915	1.65670	1.66385
N-KZFS5 654397.304	1.65412	39.70	0.016477	1.65803	39.46	0.016675	1.64649	1.64922	1.66667	1.67511	1.68318
N-KZFS8 720347.320	1.72047	34.70	0.020763	1.72539	34.47	0.021046	1.71099	1.71437	1.73637	1.74724	1.75777
N-LAF33 786441.436	1.78582	44.05	0.017839	1.79007	43.80	0.018038	1.77751	1.78049	1.79937	1.80837	1.81687
N-LASF46B 904313.451	1.90366	31.32	0.028852	1.91048	31.09	0.029289	1.89065	1.89526	1.92586	1.94130	1.95647
SF57 847238.551	1.84666	23.83	0.035536	1.85504	23.64	0.036166	1.83102	1.83650	1.87425	1.89393	1.91366
SF57HTultra 847238.551	1.84666	23.83	0.035536	1.85504	23.64	0.036166	1.83102	1.83650	1.87425	1.89393	1.91366

$P_{g,F}$	$\Delta P_{g,F}$	n_d ref.[*1]	After Molding[*2]		SR-J	WR-J	α (–30/+70)	α (20/300)	T_g	AT	ρ	HK	Abrasion Aa	τ_i (10/400)	FC
			n_d	ν_d											
0.5590	–0.0100	1.61227	1.6100	44.5	6	4	7.3	8.2	536	597	3.00	520	130	0.985	36/32
0.5605	–0.0120	1.63658	1.6341	42.3			6.6	7.6	551		3.20	530	74	0.987	36/30
0.5710	–0.0060	1.65272	1.6498	39.8	1	1	6.4	7.4	584	648	3.04	555	122	0.976	37/32
0.5833	–0.0021	1.71896	1.7158	34.8	1	1	7.8	9.4	509	561	3.20	570	152	0.963	38/33
0.5626	–0.0071	1.78425	1.7811	43.9	6	1	5.6	6.7	600	628	4.36	730	67	0.963	39/32
0.5956	0.0045	1.90165	1.8977	31.4	1	2	6.0	7.1	611	649	4.51	712	55	0.847	40/36*
0.6160	0.0123	1.84608	1.8447	23.6	6	1	8.3	9.2	414	449	5.51	350	344	0.847	40/37*
0.6160	0.0123	1.84608	1.8447	23.7	6	1	8.3	9.2	414	449	5.51	350	344	0.924	39/36*

[*1] n_d reference value (annealing rate 25 K/h) [*2] as pressed at SCHOTT; for details, please consult SCHOTT

* Wavelength for transmittance 0.7 and 0.05

Glass type	n_d	ν_d	$n_F - n_C$	n_e	ν_e	$n_{F'} - n_{C'}$	n_r	n_C	$n_{F'}$	n_g	n_h
FK3 464658.227	1.46450	65.77	0.007063	1.46619	65.57	0.007110	1.46106	1.46232	1.46978	1.47315	1.47625
N-BAF3 583466.279	1.58272	46.64	0.012495	1.58569	46.35	0.012637	1.57689	1.57899	1.59222	1.59857	1.60463
BAFN6 589485.317	1.58900	48.45	0.012158	1.59189	48.16	0.012291	1.58332	1.58536	1.59823	1.60436	1.61017
N-PSK53 620635.360	1.62014	63.48	0.009769	1.62247	63.19	0.009851	1.61547	1.61717	1.62749	1.63223	1.63662
N-SK10 623570.364	1.62278	56.98	0.010929	1.62539	56.70	0.011029	1.61759	1.61947	1.63102	1.63638	1.64137
N-SK15 623580.362	1.62296	58.02	0.010737	1.62552	57.75	0.010832	1.61785	1.61970	1.63105	1.63629	1.64116
KZFSN5 654396.346	1.65412	39.63	0.016507	1.65803	39.40	0.016701	1.64644	1.64920	1.66668	1.67512	1.68319
N-SF19 667331.290	1.66679	33.12	0.020131	1.67154	32.86	0.020435	1.65769	1.66092	1.68228	1.69309	1.70377
KZFS12 696363.384	1.69600	36.29	0.019179	1.70055	36.06	0.019425	1.68717	1.69033	1.71065	1.72059	1.73017
N-SF64 706302.299	1.70591	30.23	0.023350	1.71142	29.99	0.023720	1.69544	1.69914	1.72392	1.73657	1.74912
N-LAF3 717480.414	1.71700	47.96	0.014950	1.72055	47.68	0.015112	1.71001	1.71252	1.72834	1.73585	1.74293

$P_{g,F}$	$\Delta P_{g,F}$	**CR**	**FR**	**SR**	**AR**	**PR**	α **(−30/+70)**	T_g	$T_{10^{7.6}}$	ρ	**HK**	**HG**	τ_i **(10/400)**	**FC**
0.5329	−0.0003	2	3	52.4	2	1	8.2	362	622	2.27	380		0.994	33/30
0.5669	0.0015	1	0	1	1	1	7.2	583	714	2.79	560	2	0.959	39/35
0.5625	0.0002	2	0	2	2	1	7.8	549		3.17	540		0.971	38/33
0.5423	0.0053	2	1	52.3	1.2	4.3	9.4	618	709	3.60	440	6	0.985	36/31
0.5474	−0.0005	3	3	52.2	2	2.2	6.8	633	758	3.64	550	3	0.988	36/32
0.5453	−0.0009	3	3	52.2	2	3.2	6.7	641	752	3.62	620	3	0.984	36/31
0.5700	−0.0071	3	2	52.3	4.3	4.3	4.5	501		3.46	460	5	0.976	37/34
0.5976	0.0095	1	0	1	1.2	1	7.2	598	707	2.90	630	3	0.901	40/36
0.5778	−0.0050	4	1	53.3	4.3	4.3	5.2	492	549	3.84	440	4	0.919	40/35
0.6028	0.0099	1	0	1	1.2	1	8.5	572	685	2.99	620	4	0.850	42/37
0.5603	−0.0028	2	3	52.3	1.2	3.3	7.6	646	740	4.14	580	5	0.954	39/34

Glass type	n_d	ν_d	$n_F - n_C$	n_e	ν_e	$n_{F'} - n_{C'}$	n_r	n_C	$n_{F'}$	n_g	n_h
N-LAK33A 754523.422	1.75393	52.27	0.014424	1.75737	52.04	0.014554	1.74707	1.74956	1.76481	1.77187	1.77845
N-SF56 785261.328	1.78470	26.10	0.030071	1.79179	25.89	0.030587	1.77137	1.77607	1.80800	1.82460	1.84126
N-LAF36 800424.443	1.79952	42.37	0.018871	1.80400	42.12	0.019090	1.79076	1.79390	1.81387	1.82345	1.83252
SFL6 805254.337	1.80518	25.39	0.031708	1.81265	25.19	0.032260	1.79116	1.79609	1.82977	1.84733	1.86500
SFL57 847236.355	1.84666	23.62	0.035841	1.85510	23.43	0.036489	1.83089	1.83643	1.87451	1.89456	1.91488
SF57HT 847238.551	1.84666	23.83	0.035536	1.85504	23.64	0.036166	1.83102	1.83650	1.87425	1.89393	1.91366

Glass type	n_d	ν_d	$n_F - n_C$	n_e	ν_e	$n_{F'} - n_{C'}$	n_r	n_C	$n_{F'}$	n_g	n_h
P-PK53 527662.283	1.52690	66.22	0.007957	1.52880	65.92	0.008022	1.52309	1.52447	1.53288	1.53673	1.54029
P-SF67 907214.424	1.90680	21.40	0.042374	1.91675	21.23	0.043191	1.88833	1.89480	1.93985	1.96401	

$P_{g,F}$	$\Delta P_{g,F}$	CR	FR	SR	AR	PR	α (–30/+70)	T_g	$T_{10^{7.6}}$	ρ	HK	HG	τ_i (10/400)	FC
0.5473	−0.0086	1	1	51	1	2	5.8	669	744	4.22	740	2	0.976	38/30
0.6139	0.0140	1	0	1	1.3	1	8.7	592	691	3.28	560	5	0.799	44/37
0.5659	−0.0067	1	2	52.3	1	3.3	5.7	579	670	4.43	680	1	0.946	40/33
0.6159	0.0148	1	0	2	1	1	9.0	585		3.37	570		0.850	45/37
0.6218	0.0177	1	0	1.3	1	1.3	8.7	598	700	3.55	580	3	0.525	44/38*
0.6160	0.0123	2	5	52.3	2.3	4.3	8.3	414	519	5.51	350	1	0.847	40/37*

$P_{g,F}$	$\Delta P_{g,F}$	n_d ref.[*1]	After Molding[*2]		SR-J	WR-J	α (–30/+70)	α (20/300)	T_g	AT	ρ	HK	Abrasion Aa	τ_i (10/400)	FC
			n_d	ν_d											
0.5408	0.0084	1.52567	1.5232	66	3	1	13.3	16.0	383	418	2.83	335	977	0.994	36/31
0.6334	0.0256	1.90439	1.8998	21.6	1	1	6.2	7.4	539	601	4.24	440	309	0.276	48/39*

[*1] n_d reference value (annealing rate 25 K/h)   [*2] as pressed at SCHOTT; for details, please consult SCHOTT

* Wavelength for transmittance 0.7 and 0.05

Inquiry Glasses

Radiation Resistant Glasses

Glass type	n_d	ν_d	$n_F - n_C$	n_e	ν_e	$n_{F'} - n_{C'}$	n_r	n_C	$n_{F'}$	n_g	n_h
BK7G18 520636.252	1.51975	63.58	0.008174	1.52170	63.36	0.008233	1.51579	1.51724	1.52587	1.52981	1.53345
K5G20 523568.259	1.52344	56.76	0.009222	1.52564	56.47	0.009308	1.51906	1.52065	1.53040	1.53494	1.53919
LF5G15 584408.322	1.58397	40.83	0.014301	1.58736	40.55	0.014484	1.57739	1.57974	1.59489	1.60228	
LF5G19 597399.330	1.59655	39.89	0.014954	1.60010	39.60	0.015153	1.58970	1.59214	1.60799	1.61578	1.62330
F2G12 621366.360	1.62072	36.56	0.016979	1.62474	36.30	0.017212	1.61298	1.61573	1.63373	1.64261	1.65121
LAK9G15 691548.353	1.69064	54.76	0.012612	1.69364	54.53	0.012721	1.68462	1.68680	1.70013	1.70630	1.71205
SF6G05 809253.520	1.80906	25.28	0.032015	1.81661	25.08	0.03257	1.79491	1.79988	1.83387		

$P_{g,F}$	$\Delta P_{g,F}$	CR	FR	SR	AR	PR	α (–30/+70)	T_g	$T_{10^{7.6}}$	ρ	HK	HG	τ_i (10/400)	FC
0.5376	0.0007		0	1	2		7.0	585	722	2.52	580		0.764	41/37
0.5500	0.0017		0	1	1		9.0	483	679	2.59	510		0.821	41/37
0.5759	0.0008	2	0	1	1.3	2.3	9.3	407	578	3.22	446		0.569	43/37
0.5803	0.0036	2–3	2	3.4	2.2	3	10.7	474	606	3.30	410	2	0.276	45/39
0.5831	0.0008	1	0	1	1.3	2.3	8.1	435	604	3.60	428		0.325	45/39
0.5462	–0.0055	1–2	2	53.0	1.3	4.3	6.3	634	710	3.53	721		0.292	46/38
0.6121	0.0108	4	3	51.3	2.3	3.3	7.8	427	529	5.20	360			52/46*

* Wavelength for transmittance 0.7 and 0.05

Glossary

Glass Code	– International glass code of refractive index n_d and Abbe number ν_d with density
$\mathbf{n_x}$, ν_x, $\mathbf{n_x - n_y}$	– Refractive index, Abbe number, and dispersion at various wavelengths
$\mathbf{P_{g,F}}$, $\mathbf{\Delta P_{g,F}}$	– Relative partial dispersion and deviation of relative partial dispersion from the normal line between g and F line
CR	– Climatic resistance class
FR	– Stain resistance class
SR	– Acid resistance class (ISO 8424)
AR	– Alkali resistance class (ISO 10629)
PR	– Phosphate resistance class (ISO 9689)
α **(–30/+70)**	– Coefficient of linear thermal expansion between $-30\,°C$ and $+70\,°C$ in $10^{-6}/K$
$\mathbf{T_g}$	– Transformation temperature in °C (ISO 7884-8)
$\mathbf{T_{10^{7.6}}}$	– Temperature of the glass at a viscosity of $10^{7.6}$ dPa · s
ρ	– Density in g/cm^3
HK	– Knoop hardness (ISO 9385)
HG	– Grindability class (ISO 12844)
τ_i **(10/400)**	– Internal transmittance at 400 nm; glass thickness: 10 mm
FC	– Color Code: Wavelength for transmittance 0.80 (at*: 0.70) and 0.05; glass thickness: 10 mm (JOGIS)

Only precision molding glasses:

Abrasion Aa	– Grindability according to JOGIS
$\mathbf{n_d}$ **ref.**	– n_d reference value (annealing rate 25 K/h)
$\mathbf{n_d}$, ν_d **after molding**	– As pressed at SCHOTT (preliminary data based on annealing rate of 5000 K/h)
SR-J	– Acid resistance class according to JOGIS
WR-J	– Water resistance class according to JOGIS
AT	– Yield point/sag temperature in °C
α **(20/300)**	– Coefficient of linear thermal expansion between $+20\,°C$ and $+300\,°C$ in $10^{-6}/K$
JOGIS	– Japanese Optical Glass Industrial Standards

The data listed is the most accurate data currently available.
We reserve the right to make changes due to technical progress.

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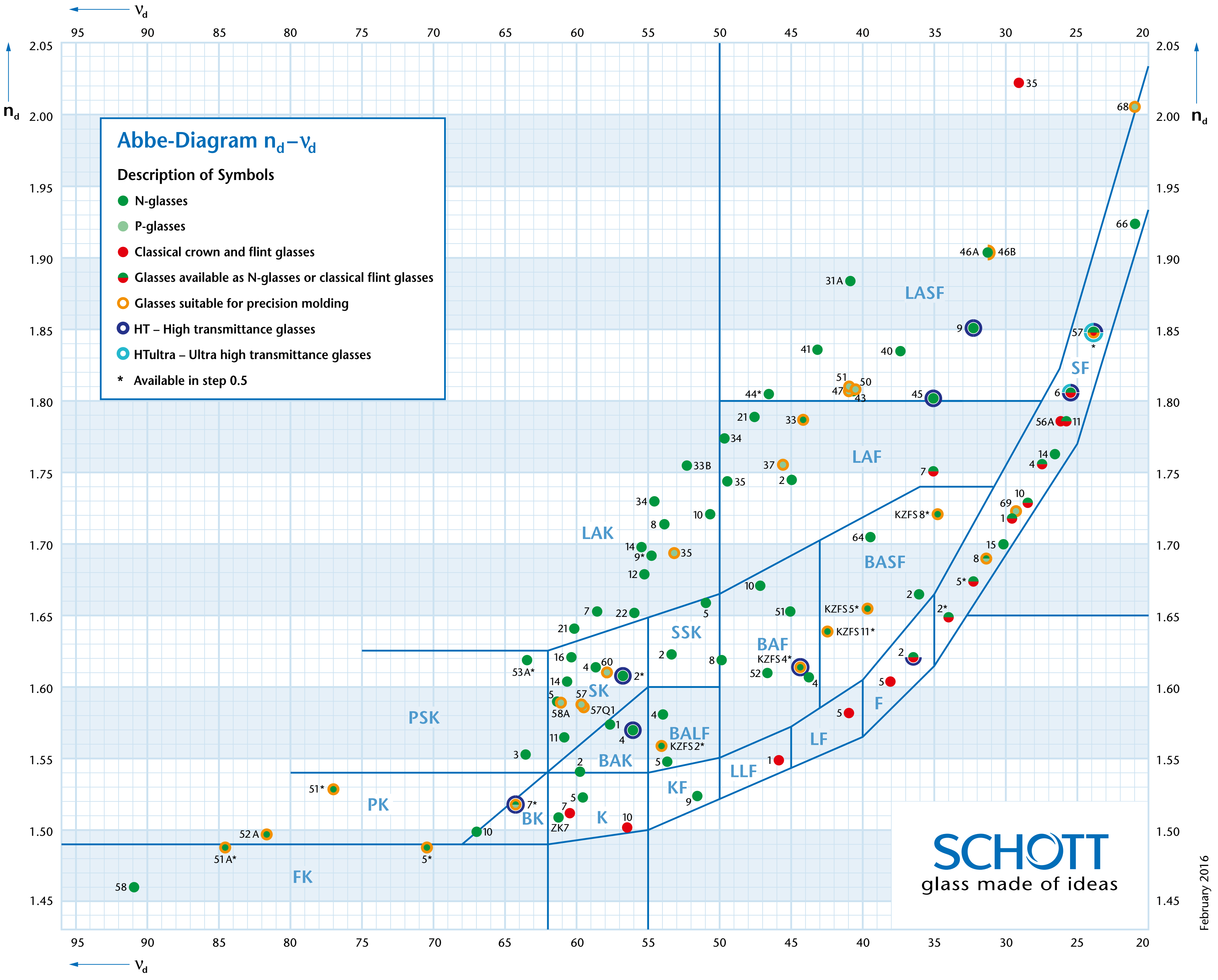
Abbe-Diagram n_d–ν_d



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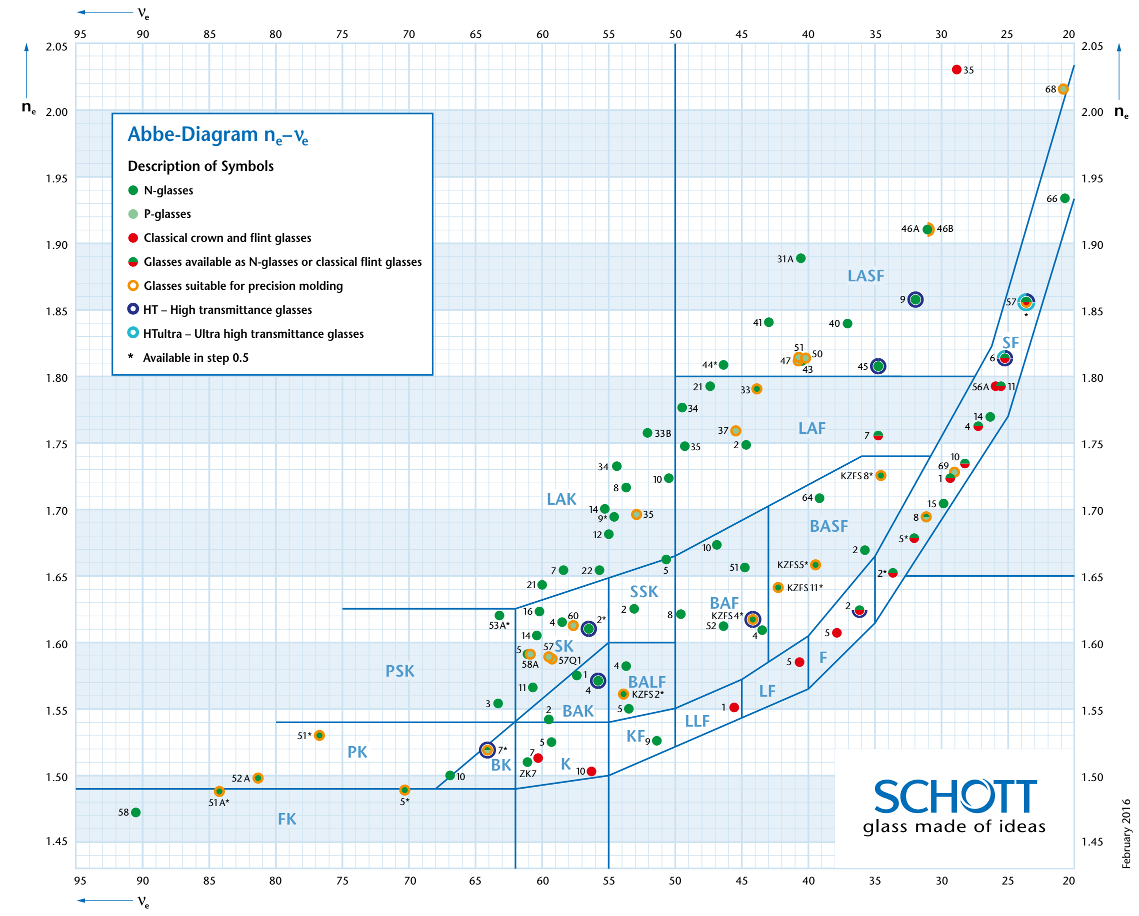
glass made of ideas

February 2016

Abbe-Diagram n_e–ν_e



$P_{g,F}$-Diagram