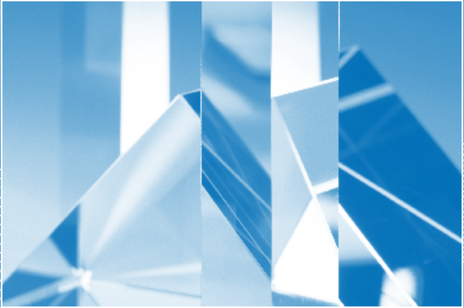
Optical Glass

Description of Properties 2009



SCHOTT
glass made of ideas

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Foreword

For more than 125 years SCHOTT offers a large variety of high quality optical glasses. They cover the needs of the broad range of optical applications from consumer products to optical systems at the leading edge of research. With this catalog we present our lead and arsenic free N-glasses and other optical materials addressing special requirements, such as:

- Low Tg glass types suited for the precision molding process
- Classical glass types with lead oxide as an essential component for outstanding optical properties
- Fused silica for optical lithographic applications with superb transmittance and radiation resistance in the UV spectral range
- Radiation resistant glass types.

Preferred materials are listed in the first part of our data section of this pocket catalog.

The second part of the data section comprises data for a selection of inquiry glass types, which are frequently requested but not to an extent that would allow SCHOTT to guarantee their availability.

The radiation resistant glass types are also listed to be inquiry glass types. Those cerium-stabilized glasses are used to maintain transmittance in ionizing radiation environment

Some optical glass types are available with improved transmittance quality in the visible spectral range especially in the blue-violet area. Those glasses are indicated with the suffix HT or HHT and have been additionally marked in the data section. Data sheets for these varieties can be found on our website.

The optical data of the UV-materials fused silica listed in this pocket catalog are meant for the use in optical applications and therefore referenced to air, like all the other optical materials in this catalog. For the use of those materials in lithography for which transmittance data below 250 nm are required we kindly request you to contact us directly in order to discuss technical aspects more in detail. That applies also for i-line glasses, which are used for lithography due to their superb transmittance in the near UV-range and in optical homogeneity. We would be pleased to offer respective data sheets and technical support upon your request.

The production, processing and distribution of our product range of materials is in accordance with our Integrated Management System for Safety and Environmental Protection (IMSU) preventing environmental pollution and preserving natural resources.

Beyond the content of this catalog SCHOTT also produces other optical materials like colored glasses, infrared transmitting glasses and the zero expansion glass ceramic ZERODUR®, for which we would be pleased to offer technical support and catalogs or product information upon your request.

For more information about our optical materials, their properties, the detailed data sheets, data bases for use with optical design programs and survey diagrams please visit the download page of our web site.

1 Optical Properties

1.1 Refractive index, Abbe number, dispersions, glass designations

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 called the principal dispersion.

Optical glass can also be designated by a numerical code, often called glass code. SCHOTT uses a nine-digit code. The first six places 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 value ν_d. The additional three digits indicate the density of the glass.

Table 1.1: Examples for glass code

Glass type	n_d	ν_d	Density	Glass code
N-SF6	1.80518	25.36	3.37	805254.337 lead-arsenic free glass
SF6	1.80518	25.43	5.18	805254.518 classical lead silicate glass

When specifying optical systems the values based on the e-line n_e and $\nu_e = (ne - 1)/(n_{F'} - n_{C'})$ 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 order of decreasing Abbe values in the data section.

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 step 4 for ν_d. We will supply material in tighter steps upon demand.

Tab. 1.2: Tolerances for refractive index and Abbe number

	n_d	ν_d
Step 4	–	± 0.8 %
Step 3	± 0.0005	± 0.5 %
Step 2	± 0.0003	± 0.3 %
Step 1	± 0.0002	± 0.2 %

All deliveries of fine annealed optical glass and cut blanks are made in lots of single batches.

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 given 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 given in the following table 1.3. If requested, parts can also be supplied in lots with tighter refractive index variation as indicated in table 1.3.

Table 1.3: Tolerance of refractive index variation within a lot of fine annealed glass and within a lot of pressings

Fine annealed glass, cut blanks		Pressings	
Designation	**Refractive index variation**	**Designation**[1)]	**Refractive index variation**
SN	$\pm 1 \times 10^{-4}$	LN	$\pm 2 \times 10^{-4}$
S0	$\pm 5 \times 10^{-5}$	LH1	$\pm 1 \times 10^{-4}$
S1	$\pm 2 \times 10^{-5}$	LH2	$\pm 5 \times 10^{-5}$

[1)] All variation tolerances for pressings upon request only

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 based on sampling tests refers to the median position of the optical values of a delivery lot. The value of the individual part may deviate from the reported median value by the tolerance of refractive index variation.

The measurements are performed with an accuracy of $\pm 3 \times 10^{-5}$ for refractive index and $\pm 2 \times 10^{-5}$ for dispersion. The numerical data are listed to 5 decimal places.

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

n_d	ν_d	$n_F - n_C$	$n_F - n_d$	$n_{F'} - n_{C'}$	$n_g - n_F$
n_e	ν_e	$n_d - n_C$	$n_F - n_e$	$n_{F'} - n_e$	

Test certificates with enhanced accuracy can be provided for individual glass parts upon request ($\pm 2 \times 10^{-5}$ for refractive index and $\pm 1 \times 10^{-5}$ for dispersion). These certificates additionally 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 refer to individual glass parts in any case.

Within the visible spectral range these certificates contain the same quantities as the test reports for standard accuracy but with the difference that the dispersion data is reported to 6 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.

The measurement is done with a prism goniometer. The accuracy is $\pm 1 \times 10^{-5}$ for refractive index and $\pm 3 \times 10^{-6}$ for dispersion. An accuracy of up to $\pm 4 \times 10^{-6}$ for the refractive index and $\pm 2 \times 10^{-6}$ for the dispersion measurement, independent of the glass type and measurement wavelength, can be provided on request.

The standard measurement temperature is 22°C. The measurement temperature can be changed to a constant value between 18 and 28°C on request. The standard measurement atmosphere is air at a pressure of 1013.3 hPa. On special request measurement in nitrogen is possible.

1.4 Refractive index homogeneity

The refractive index homogeneity is a measure to designate deviations of refractive index within individual pieces of glass. With special efforts in melting and fine annealing pieces of glass with a high homogeneity of refractive index can be obtained. The achievable refractive index homogeneity depends on the glass type, on the volume and the shape of the individual glass piece.

The required optical homogeneity should be specified with respect to application and final dimension of the part. In general the optical homogeneity values specified are peak to valley values calculated from measured wave front deviations containing all aberrations. In many cases it is acceptable to subtract certain aberration terms of negligible impact on the application. 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.

Increased requirements for refractive index homogeneity comprises 5 classes in accordance with the standard ISO 10110 Part 4 (see table 1.5). For class 0 of the standard, please refer to the tolerances of refractive index variation in section 1.2.

Table. 1.5: Homogeneity of optical glasses

Homogeneity class	**Maximum variation of refractive index**	**Applicability, deliverability**
H 1	$\pm 2 \times 10^{-5}$	For individual cut blanks
H 2	$\pm 5 \times 10^{-6}$	For individual cut blanks
H 3	$\pm 2 \times 10^{-6}$	For individual cut blanks, not in all dimensions.
H 4	$\pm 1 \times 10^{-6}$	For individual cut blanks, not in all dimensions, not for all glass types.
H 5	$\pm 5 \times 10^{-7}$	For individual cut blanks, not in all dimensions, not for all glass types.

1.5 Internal transmittance, color code

The internal transmittance, i. e. the light transmittance excluding reflection losses, is closely related to the optical position of the glass type according to general dispersion theory. 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 economical reasonable limits.

The internal transmittance and the color code given in the data section comprises median values from several melts of a glass type. Upon special request minimum values for internal transmittance can be maintained also for all glass types. Prior clarification of the delivery situation is required. The internal transmittance at 400 nm for a sample thickness of 10 mm is listed in the data section.

Some glasses are available with improved transmittance (like N-SF6HT or SF57HHT) in the visible spectrum especially in the blue violett range. Such glasses are indicated with the suffix HT (high grade transmittance) or HHT (highest grade transmittance) and will be marked separately in the data section. For HT and HHT grade the internal transmittance in the visible spectrum comprises guaranteed minimum values.

The limit of the transmittance ranges of optical glasses towards the UV area is of special interest in high index glasses as it shifts closer to the visible spectral range with increasing refractive index. A simple description of the position and slope of the UV absorption curve is given 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 10 mm thickness. The values are rounded to 10 nm and are noted by eliminating the first digit. Color code 33/30 means, for example $\lambda_{80} = 330$ nm and $\lambda_5 = 300$ nm.

For high index glass types with $n_d > 1.83$ the data of the color codes (marked by *) refer to the transmittance values 0.70 and 0.05 (λ_{70} and λ_5) because of the high reflection loss of this glass.

2 Internal Properties

2.1 Striae

Deviations of the refractive index in glass of short range are called striae.

They resemble bands in which the refractive index deviates with a typical period of tenths to several millimeters.

The standard ISO 10110 Part 4 contains a classification with reference to striae. Since it refers to finished optical components, it is only conditionally applicable to optical glass in its original form of supply. It evaluates the striae into classes 1–4 according to their area based on the optically effective total surface of the component. Thereby, 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, but directs the user to make arrangements with the glass manufacturer.

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

SCHOTT generally uses the shadow graph method to test all optical glasses. This very sensitive method characterizes optical glass, even for the most stringent requirements.

Quality step VS1 specifies optical glass with increased striae selection. For optical glass within this quality step no striae have been detected by the sensitive shadow method. For prism applications SCHOTT offers quality step VS2. For such glass parts no striae have been detected by the shadow method in two directions perpendicular to one another.

2.2 Bubbles and inclusions

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

The bubble content is described 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 like bubbles of the same cross section. The evaluation considers all bubbles and inclusions $\geq$ 0.03 mm.

The bubble classes and the maximum allowable quantities and diameters of bubbles and inclusions are listed in table 2.1. 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 allowable.

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

Table 2.1: Tolerances for bubbles and inclusions in optical glasses

Bubble class **Quality step**		**B0**	**B0** **VB**	**B0** **EVB**	**B1**	**B1** **VB**	**B1** **EVB**
Maximum allowable cross section of all bubbles and inclusions in mm^2 per 100 cm^3 of glass volume		0.03	0.01	0.006	0.1	0.03	0.02
Maximum allowable quantity per 100 cm^3		10	4	2	30	10	4
Maximum allowable	50	0.10	0.10	0.10	0.15	0.15	0.10
diameter of bubbles	100	0.15	0.15	0.10	0.20	0.15	0.10
or inclusions in mm	200	0.20	0.15	0.10	0.30	0.20	0.10
within parts of **diameter**	300	0.25	0.20	–	0.40	0.25	–
or max. edge length	500	0.40	–	–	0.60	–	–
in mm.	800	0.55	–	–	0.80	–	–

2.3 Stress birefringence

Size and distribution of permanent inherent stress in glass depends on the annealing conditions, the glass type, and the dimensions. The extend of 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. The measurement is performed on round discs at a distance of 5% of the diameter from the edge. For rectangular plates the measurement is performed in the center of the longer side at a distance of 5% of the plate width. A detailed description of the method can be found in ISO Standard 11455.

The de Sénarmont and Friedel method is insufficient for measurements of low stress birefringence and low thickness. In these cases we have methods to measure an order of magnitude more accurately instead.

With our annealing methods we are able to achieve both, high optical homogeneity and very low stress birefringence. Pieces of glass to be delivered generally have a symmetrical stress distribution. The glass surface is usually in compression. The stress birefringence is considerably reduced when block or strip glass is cut. If the optical elements are much smaller than the raw glass format from which they were made, then the remaining stress birefringence is even much lower than the limiting values shown in table 2.2.

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

Higher stresses are permitted in glass used for reheat pressing. The mechanical processing is not affected by this.

Table 2.2: 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

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. On the surface of sensitive glasses a film of white stains can develop that generally cannot be wiped off.

Table 3.1: Classification of optical glasses into 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 %

An accelerated procedure according to ISO/WD 13384 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 is alternated between 40°C and 50°C. This produces a periodical change from moist condensation on the glass surface and subsequent drying.

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

The glasses in class CR 1 display no visible attack after being exposed for 30 hours to climatic change. In normal humidity conditions during the fabrication and storing of optical glass in class CR 1, no surface attack should be expected. On the other hand, the fabrication and storing of optical glasses in class CR 4 should be done with caution because these glasses are very sensitive to climatic influences.

For storage of optical polished elements we recommend to apply a protective coating and/or assure that relative humidity is kept as low as possible.

3.2 Stain resistance

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

The stain resistance class is determined according to the following procedure: The plane polished glass sample to be tested is pressed onto a test cuvette, which has a spherical depression of max. 0.25 mm depth containing a few drops of 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, which were determined on reference samples previously. A brown-blue change in color indicates a chemical change in the surface layer of 0.1 µm thickness insofar the glass can form layers at all. Table 3.2 lists the stain resistance classes.

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

Stain resistance class FR	**0**	**1**	**2**	**3**	**4**	**5**
Test solution	I	I	I	I	II	I/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 exhibit 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 classifies 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 ISO 8424 (1996).

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

The time t 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 less acid resistance are exposed to a weak acidic solution with 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.

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.

Table 3.3: Classification of optical glasses into 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

3.4 Alkali resistance and phosphate resistance

Both test methods serve 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 ISO 10629 (1996).

The phosphate resistance describes the behavior of optical glass during cleaning with phosphate containing washing solutions (detergents). Phosphate resistance is determined according ISO 9689 (1990).

The alkali as well as the 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 through exposure.

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

The phosphate resistance class PR indicates the time required to remove a layer thickness of glass of 0.1 µm in an alkaline phosphate containing solution (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.

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

Glasses in class 1 are more resistant to the test solutions than glasses in class 4. The digit behind the classification identifies the visible surface change which occurred through exposure. The digits are enumerated in Chapter 3.5.

3.5 Identification of visible surface changes

Changes in the surfaces of the exposed samples are qualitatively evaluated 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 loosely adhering, thick layer, such as insoluble, friable surface deposit (maybe a cracked and/or peel able surface, surface crust, or cracked surface; strong attack)

3.6 Environmental aspects, hazardous substances, RoHS

The production, processing and distribution of our product range of materials is in accordance with our Integrated Management System for Safety and Environmental Protection (IMSU) preventing environmental pollution, preserving natural resources and follows the procedure and philosophy of the Quality Management System.

The handling of raw material, melting of the batches and hot forming adheres to established safety procedures. Sludge from cutting, grinding and polishing must be treated according to waste disposal procedures prescribed by local authorities. Glass parts survive their end of usage life by far without releasing any of their chemical components. Their disposal is a rare and dispersed event thus preventing any accumulation to critical levels by far.

All optical materials in this catalog comply with the requirements of the European Directive 2002/95/EC (RoHS). Mercury (Hg), chromium VI (CrVI), cadmium and the flame retardants PBB and PBDE are not present in the optical materials of our catalog at all. N- and P-glass types comply with the limit value of 0.1% for lead given in the directive 2005/618/EC stating the admissible limits for the hazardous substances quoted in RoHS. The classical glass types may contain lead oxide in significant amounts. They are in compliance with RoHS due to the exemption documented in the Commission decision 2005/747/EC. In addition all materials in this catalog comply with the requirements of the European Regulation 2006/1907/EC (REACH: Registration, Evaluation and Authorization of Chemical Substances).

4 Mechanical Properties

4.1 Knoop hardness

The Knoop hardness indicates the amount of surface changes on a material after indentation of a test diamond at 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 to 10 HK 0.1/20. The micro hardness is a function of the magnitude of the test force and decreases with increasing test force.

4.2 Grindability (ISO 12844)

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

The classification occurs 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 in the lower classifications is less and is 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 liquid to 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 possibility for identifying the transformation range is 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 Tg. 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 thermal treatment.

4.4 Coefficient of linear thermal expansion

The typical curve of linear thermal expansion of glass starts near absolute zero with an increase in slope to approximately room temperature. Then a nearly linear increase to the beginning of the noticeable plastic behavior follows. The transformation range is distinguished by a distinct bending of the expansion curve that results from the increasing structural movement in the glass. Above this range the expansion again exhibits a nearly linear increase, 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 given for the following temperature ranges:

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

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

5 Thermal Properties

5.1 Thermal conductivity

The range of values for thermal conductivity for glasses at room temperature extends from 1.38 W/(m·K) (pure quartz glass) to about 0.5 W/(m·K) (high lead containing glasses). 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

The mean isobaric specific heat capacity cp (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 cp (20°C; 100°C) and also for the true heat capacity cp (20°C) for silicate glasses lies in-between 0.42 and 0.84 J/(g·K).

6 Delivery Quality

6.1 Standard delivery quality

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

6.2 Increased delivery quality

Increased quality steps will be offered according to the following table.

Table 6.1: Increased quality steps for various forms of supply

	Glass for hot processing	Pressings	Fine annealed glass	Cut blanks
Refractive index – Abbe number steps	2, 1 3, 2, 1	2, 1 3, 2, 1	2, 1 3, 2, 1	2, 1 3, 2, 1
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 a 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	–	–	–	H1 – H5
Stress birefringence	–	SK	SK	SK, SSK
Striae	–	VS	–	VS1, VS2
Bubbles/inclusions	–	VB, EVB	–	VB, EVB
Remarks			One surface can be worked	Striae and homogeneity measured in the same direction

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

We recommend to check availability with us as soon as possible.

Requirements that exceed the mentioned quality steps may also be met. Please inquire.

7 Forms of Supply and Tolerances

7.1 Raw glass

7.1.1 Blocks

Blocks have five unworked, as-cast surfaces. Usually at least one surface is worked. The edges are rounded. Blocks are fine annealed and therefore suitable for cold working.
Described by: *Length, width, thickness.*

7.1.2 Strips

Strips have unworked 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.*

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 inquire.

We achieve surface roughness of Rt = 20 – 25 µm with standard processing.
Plates with closer dimensional tolerances and finer surfaces are possible upon request.

7.2.2 Round plates

Round plates are cylindrical parts for which the diameter is larger than the thickness. Round plates are machined at all surfaces.
Described by: *Diameter, thickness.*

Table 7.2: Dimensional tolerances and minimum dimensions for round plates

Diameter [mm]	Admissible tolerances				Minimum thickness[1)] [mm]
	For diameter		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	± 0.3	± 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 thickness than listed is possible. Please inquire.

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

7.2.3 Rods, worked

Worked rods are cylindrical parts that are machined at all sides. The length of a rod is always greater than the 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 per 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 eventually be grinded on all sides. Using different fabrication technologies, equilateral and non-equilateral prisms can be produced in various forms (ridge-, penta-, triple prisms …).
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 mostly round cross section, with defined radii and bevels.
Described by: *Diameter, center thickness, radius 1, radius 2, bevels.*

Table 7.5: Dimensions and tolerances for pressed blanks according to DIN 58 926, Part 2

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/–0.18	±0.4	2	1	0.6 * Ø
> 18–30	+0/–0.25	±0.4	3	1.5	0.45 * Ø
> 30–60	+0/–0.3	±0.3	5	3	0.4 * Ø
> 60–90	+0/–0.4	±0.3	6	4	0.3 * Ø
> 90–120	+0/–0.6	±0.4	7	5	0.3 * Ø
> 120–140	+0/–0.7	±0.5	8	5	0.3 * Ø
> 140–180	+0/–0.9	±0.5	8	6	0.3 * Ø
> 180–250	+0/–1.15	±0.5	10	8	0.3 * Ø
> 250–320	+0/–1.5	±0.6	10	8	0.3 * Ø

7.3.2 Pressed prisms

Pressed prisms are hot-formed parts with angled, prismatic shape. Other dimensions are possible upon request.
Described by: *drawing.*

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		2
> 30–60	±0.3	±0.4		2
> 60–90	±0.4	±0.5	±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

8 Optical Glasses for Precision Molding

Precision molding technology for direct pressing of aspherical lenses or freeform surfaces in general have gained increasing importance in the past years worldwide. During a precision molding process, a glass preform with a very good 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 typical temperatures between 500°C and 700°C. Low temperature processes help to lengthen the operating lifetime of the mold material.

P-glasses are new developed low transformation temperature glasses especially for precision molding. The letter "P" indicates that these glasses are exclusively produced for precision molding and that they are lead and arsenic free. Additionally several traditional optical glasses have been identified to be suitable for precision molding mainly because of their low glass transition temperature.

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

The rapid cooling rate of a precision molding process leads to an index drop lowering 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 2 K/h reference annealing rate. The extent of index drop depends on the process, the glass type and the geometry of the part.

The available optical glasses suitable for precision molding are displayed in the data section of this pocket catalog, which contains the new developed P-glasses but also the traditional glasses that are suitable for precision molding. The data section for low Tg glasses also contains some additional information. The acid resistance according JOGIS (Japanese Optical Glass Industrial Standard), the water resistance according JOGIS and the yield point/sag temperature of the glass.

9 Product Range of Optical Materials

9.1 Preferred materials

The materials listed in the first part of the data section are preferred materials. They are produced without a specific customer order and are in general kept on stock for immediate delivery. For those materials we guarantee reliable and long-term supply. Preferred materials are therefore recommended for use of designs in new optical systems and are 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 web site.

9.2 Inquiry glasses

The second part of the data section comprises inquiry glasses, which are regularly produced upon your specific request. For some of those glasses we might have stock available from previous long running projects. However, stock is not purposely generated without a customer order. If there is no stock available we will offer upon your request.

10 Collection of Formulas and Wavelength Table

Relative partial dispersion Px, 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 glass types K7 and F2.

Sellmeier dispersion formula

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

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

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

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

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

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

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

Spectral internal transmittance

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

Spectral transmittance

$$\tau_{\lambda} = \tau_{i\lambda} \cdot P_{\lambda} \tag{10.16}$$

P_{λ} factor of reflection.

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

$$R = ((n-1) / (n+1))^2 \tag{10.17}$$

Reflection factor considering multiple reflections

$$P = (1-R)^2 / (1-R^2) = 2n / (n^2+1) \tag{10.18}$$

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 the thicknesses d_1 and d_2

Stress birefringence, difference optical path

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

K Stress optical constant, dependent on glass type in $10^{-6}\ mm^2/N$

d Length of light path in the sample in cm

σ Mechanical stress (positive for tensile stress) in N/mm^2 (= MPa)

Homogeneity from interferometrically measured wave front deviations

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

$$= \Delta W\,[\lambda] \cdot 633 \cdot 10^{-6} / (2 \cdot d[mm])$$

when listing the wave front deformation in units of the wavelength and a test wavelength of 633 nm (He-Ne laser)

ΔW Wave front deformation with double beam passage (interferometric testing)

d Thickness of test piece

Note: The formulas have been carefully chosen and listed.
However, SCHOTT can not be made responsible for errors resulting from their use.

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

Table 10.1: Wavelengths for a selection of frequently used spectral lines.

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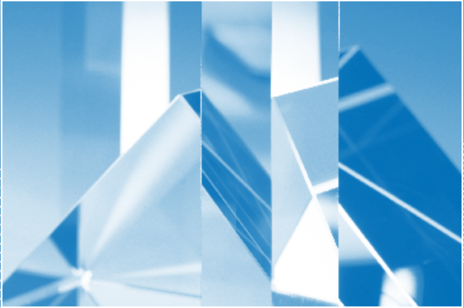
Optical Glass

Properties 2009



SCHOTT
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Properties

Glass Code – International glass code of refractive index n_d and Abbe number ν_d with density

n_x, ν_x, $n_x - n_y$ – Refractive index, Abbe number, and dispersion at various wavelengths

$P_{g,F}$, $\Delta P_{g,F}$ – Relative partial dispersion and deviation of relative partial dispersion from normal line between g and F line

CR – Climatic resistance class (ISO/WD 13384)

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

T_g – Transformation temperature in °C (ISO 7884-8)

$T_{10^{7.6}}$ – 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)

B – Bubble class

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:

SR-J – Acid resistance class according JOGIS

WR-J – Water resistance class according JOGIS

AT – Yield point/sag temperature in °C

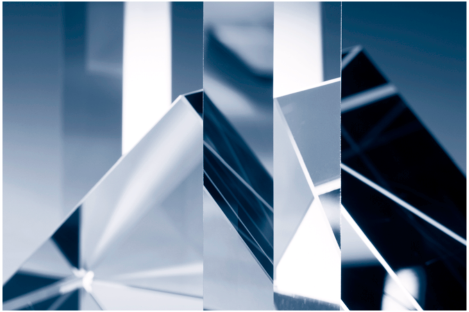
α(20/300) – Coefficient of linear thermal expansion between +20 °C and +300 °C in 10^{-6}/K

JOGIS – Japanese Optical Glass Industrial Standards

The data are the best currently known.
We reserve the right of changes due to technical progress.

Optical Glass

Properties 2009



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glass made of ideas

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	$P_{g,F}$	$\Delta P_{g,F}$
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	0.5290	0.0036
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	0.5359	0.0342
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	0.5401	0.0258
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	0.5377	0.0311
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	0.5365	–0.0005
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	0.5424	0.0052

FK
PK
PSK

CR	FR	SR	AR	PR	α (–30/+70)	T_g	$T_{10^{7.6}}$	ρ	HK	HG	B	τ_i (10/400)	FC
2	1	4	2	2.3	9.2	466	672	2.45	520	3	1	0.998	30/27
1	0	52.3	2.2	4.3	12.7	464	527	3.68	345	6	1	0.997	34/28
1	0	52.3	3.3	4.3	12.4	487	568	3.86	415	6	1	0.994	34/29
1	0	52.3	3.3	4.3	13.0	467	538	3.70	355	6	1	0.997	34/28
3	0	2.2	2	2	6.2	599	736	2.91	630	2	1	0.994	33/28
1	1	53.3	2.3	4.3	9.6	606	699	3.57	415	6	1	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	$P_{g,F}$	$\Delta P_{g,F}$
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	0.5349	–0.0009
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	0.5303	–0.0008
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	0.5438	0.0000
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	0.5422	0.0000
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	0.5475	–0.0015
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	0.5370	–0.0039

CR	FR	SR	AR	PR	α (−30/+70)	T_g	$T_{10}^{7.6}$	ρ	HK	HG	B	τ_i (10/400)	FC
1	0	1	2.3	2.3	7.1	557	719	2.51	610	3	0	0.997	33/29
1	0	1	1	1	5.8	551	753	2.39	560	4	1	0.996	31/27
1	0	1	1	1	8.2	546	720	2.59	530	3	1	0.995	34/30
3	0	2	1	2.3	8.4	513	712	2.53	520	3	1	0.996	33/30
1	0	1	1	1.2	6.5	459	691	2.52	470	4	1	0.994	33/30
1	0	2	1.2	2.2	4.5	539	721	2.49	530	4	1	0.990	34/29

BK
K
ZK

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	$P_{g,F}$	$\Delta P_{g,F}$
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	0.5472	0.0002
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	0.5437	0.0004
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	0.5487	–0.0010
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	0.5477	–0.0008
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	0.5448	–0.0004
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	0.5400	–0.0007
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	0.5411	–0.0004
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	0.5415	–0.0003
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	0.5412	–0.0011

CR	FR	SR	AR	PR	α (–30/+70)	T_g	$T_{10^{7.6}}$	ρ	HK	HG	B	τ_i (10/400)	FC
2	1	3.3	1.2	2	7.6	592	746	3.19	530	2	1	0.996	33/29
2	0	1	1	2.3	8.0	554	727	2.86	530	2	1	0.997	32/28
1	0	1.2	1	1	7.0	581	725	3.05	550	2	0	0.992	36/33
2	0	2.2	1	2.3	6.0	659	823	3.55	550	2	0	0.994	35/30
3	1	51.2	2	2	6.5	658	769	3.54	580	3	1	0.990	36/32
3	1	4.4	2	1.3	5.5	660	791	3.30	590	3	1	0.992	34/29
2	0	2	1	2.3	6.5	610	760	3.08	570	2	1	0.990	34/29
4	2	51.3	2	2.3	6.0	649	773	3.44	600	3	1	0.990	35/29
4	4	53.3	3.3	3.2	6.3	636	750	3.58	600	4	1	0.988	36/30

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	$P_{g,F}$	$\Delta P_{g,F}$
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	0.5558	–0.0014
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	0.5520	–0.0012
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	0.5532	–0.0004
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	0.5526	–0.0016
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	0.5575	–0.0007
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	0.5602	0.0002
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	0.5433	–0.0021
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	0.5450	–0.0083

CR	FR	SR	AR	PR	α (−30/+70)	T_g	$T_{10^{7.6}}$	ρ	HK	HG	B	τ_i (10/400)	FC
1	0	1	1	1	9.6	476	640	2.50	480	1	1	0.986	37/34
1	0	1	1	1	6.5	578	661	3.11	540	2	1	0.985	37/33
1	0	1	2	1	7.3	558	711	2.61	600	2	1	0.983	37/34
1	0	1.2	1	1	5.8	653	801	3.53	570	3	1	0.981	37/33
2	3	52.2	2.2	3.2	6.8	645	751	3.71	590	5	1	0.959	38/34
1	0	1	1.3	1	7.2	616	742	3.27	570	3	1	0.950	39/35
3	2	53.3	3.3	4.3	7.1	618	716	3.84	600	5	0	0.977	37/30
3	2	52.3	1	3.3	5.6	643	717	3.75	740	2	0	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	$P_{g,F}$	$\Delta P_{g,F}$
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	0.5447	−0.0071
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	0.5515	−0.0072
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	0.5485	−0.0024
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	0.5427	−0.0079
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	0.5411	−0.0017
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	0.5467	−0.0031
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	0.5473	−0.0086
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	0.5443	−0.0079

CR	FR	SR	AR	PR	α (−30/+70)	T_g	$T_{10^{7.6}}$	ρ	HK	HG	B	τ_i (10/400)	FC
3	3	52	1.2	4.3	6.3	656	722	3.51	700	3	0	0.980	37/30
2	2	52.3	1	3	5.7	636	714	3.69	780	2	0	0.959	39/34
3	1	53.3	3.3	4.3	7.6	614	714	4.10	560	6	1	0.976	37/31
3	2	52.3	1	3	5.5	661	734	3.63	730	2	0	0.981	37/29
4	2	53.2	4.3	4.3	6.8	639	716	3.74	600	5	0	0.979	37/31
2	2	51.2	1	2.3	6.6	689		3.77	600	4	0	0.985	36/30
1	1	51	1	2	5.8	669	744	4.22	740	2	0	0.976	38/30
1	0	52.3	1	3.3	5.8	668	740	4.02	740	2	0	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	$P_{g,F}$	$\Delta P_{g,F}$
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	0.5660	–0.0009
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	0.5733	0.0030
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	0.5629	–0.0016
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	0.5670	–0.0012
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	0.5678	0.0024

CR	FR	SR	AR	PR	α (–30/+70)	T_g	$T_{10^{7.6}}$	ρ	HK	HG	B	τ_i (10/400)	FC
1	0	1	2	1	8.1	431	628	2.94	450	3	1	0.997	33/31
1	0	1	1.2	1.3	7.2	580	709	2.89	610	3	1	0.946	39/35
1	0	4.3	1.3	1	6.2	660	790	3.75	620	4	1	0.950	39/35
2	0	5.4	1.3	1	8.4	569	712	3.33	560	5	1	0.954	39/34
1	0	1	1.3	1	6.9	594	723	3.05	600	3	1	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	$P_{g,F}$	$\Delta P_{g,F}$
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	0.5748	–0.0003
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	0.5881	0.0056
F2[H] 620364.360	1.62004	36.37	0.017050	1.62408	36.11	0.017284	1.61227	1.61503	1.63310	1.64202	1.65064	0.5828	0.0002
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	0.5795	–0.0003
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	0.5890	0.0057
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	0.5769	–0.0006

[H] Also available in HT or HHT quality.

CR	FR	SR	AR	PR	α (−30/+70)	T_g	$T_{10^{7.6}}$	ρ	HK	HG	B	τ_i (10/400)	FC
2	0	1	2.3	2	9.1	419	585	3.22	450	2	1	0.997	34/31
1	0	1	1	1	7.8	569	686	2.65	600	2	1	0.946	39/36
1	0	1	2.3	1.3	8.2	434	594	3.60	420	2	0	0.994	35/32
1	0	1	2.3	2	8.0	438	608	3.47	450	3	0	0.993	35/32
1	0	1	1	1	7.1	619	766	3.15	580	3	1	0.891	41/36
1	0	3.2	1.2	1	7.3	582	712	3.20	650	4	0	0.924	40/35

LF
F
BASF

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	$P_{g,F}$	$\Delta P_{g,F}$
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	0.5656	−0.0027
N-LAF7 749348.373	1.74950	34.82	0.021525	1.75459	34.56	0.021833	1.73972	1.74320	1.76602	1.77741	1.78854	0.5894	0.0042
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	0.5825	−0.0025
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	0.5555	−0.0084
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	0.5626	−0.0071
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	0.5518	−0.0085
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	0.5523	−0.0084
N-LAF36[i] 800424.443	1.79952	42.37	0.018871	1.80400	42.12	0.019090	1.79076	1.79390	1.81387	1.82345	1.83252	0.5659	−0.0067

[i] Will become inquiry glass as of 2014/01/01. Not recommended for new design.

CR	FR	SR	AR	PR	α (−30/+70)	T_g	$T_{10}{}^{7.6}$	ρ	HK	HG	B	τ_i (10/400)	FC
2	3	52.2	1	2.2	8.1	653	742	4.30	530	6	1	0.933	40/34
1	2	51.3	1.2	1.2	7.3	568	669	3.73	530	5	1	0.752	46/36
3	1	53.3	2.2	4.3	5.3	500	573	4.38	520	3	0	0.937	40/35
1	1	51.3	1	1.3	6.0	653	729	4.28	730	2	1	0.950	40/33
1	2	52.2	1	3	5.6	600	673	4.36	730	1	0	0.957	39/32
1	1	51.3	1	1	5.8	668	745	4.24	770	2	0	0.967	39/32
2	1	52.3	1	3.3	5.3	589	669	4.12	660	2	0	0.976	38/30
1	2	52.3	1	3.3	5.7	579	670	4.43	680	1	0	0.946	40/33

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	$P_{g,F}$	$\Delta P_{g,F}$
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	0.5934	0.0037
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	0.5667	–0.0085
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	0.5786	–0.0024
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	0.5629	–0.0083
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	0.5703	–0.0052
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	0.5572	–0.0084
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	0.5859	0.0009
N-LASF46A 904313.463	1.90366	31.32	0.028853	1.91048	31.09	0.029287	1.89064	1.89526	1.92586	1.94129	1.95645	0.5953	0.0042

CR	FR	SR	AR	PR	α (–30/+70)	T_g	$T_{10}{}^{7.6}$	ρ	HK	HG	B	τ_i (10/400)	FC
1	0	2	1	1	7.4	683	817	4.41	515	4	1	0.799	41/36*
1	0	2.3	1	1	6.7	719	830	5.51	650	2	1	0.924	38/33*
1	1	51.2	1	1.3	5.8	590	677	4.43	580	1	0	0.891	39/35*
1	1	4	1	1	6.2	651	739	4.85	760	2	0	0.948	37/32*
1	1	51.3	1	2	5.5	614	699	4.26	720	2	1	0.919	42/34
1	1	4	1	1	6.2	655	742	4.44	770	2	0	0.963	40/31
1	0	3.2	1	1	7.4	647	773	3.63	630	3	0	0.857	44/35
1	0	3.3	1	1	6.0	635	735	4.45	730	1	0	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	$P_{g,F}$	$\Delta P_{g,F}$
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	0.6037	0.0097
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	0.5950	0.0081
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	0.6096	0.0118
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	0.5984	0.0088
N-SF6[H] 805254.337	1.80518	25.36	0.031750	1.81266	25.16	0.032304	1.79114	1.79608	1.82980	1.84738	1.86506	0.6158	0.0146
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	0.5999	0.0087
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	0.6066	0.0108
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	0.6156	0.0150
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	0.6122	0.0130
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	0.6038	0.0108
N-SF57[H] 847238.353	1.84666	23.78	0.035604	1.85504	23.59	0.036247	1.83099	1.83650	1.87432	1.89423	1.91440	0.6216	0.0178

[H] Also available in HT or HHT quality.

CR	FR	SR	AR	PR	α (–30/+70)	T_g	$T_{10^{7.6}}$	ρ	HK	HG	B	τ_i (10/400)	FC
1	0	1	1	1	9.1	553	660	3.03	540	5	1	0.867	41/36
1	0	1	1.2	1	6.7	608	731	2.72	539		1	0.928	40/36
1	0	1.3	1	1	9.5	570	661	3.15	520	6	1	0.787	44/37
1	0	1	1	1	7.9	578	693	2.86	620	3	1	0.905	40/36
1	0	2	1	1	9.0	589	683	3.37	550	4	0	0.821	45/37
1	0	1	1	1	8.6	567	678	2.90	600	4	1	0.901	41/36
1	0	1	1	1	9.4	559	652	3.05	540	5	1	0.837	42/36
1	0	1	1	1	8.5	592	688	3.22	615	4	1	0.815	44/37
1	0	1	1	1	9.4	566	657	3.12	515	5	0	0.891	42/36
1	0	1	1	1	8.0	580	692	2.92	610	3	1	0.857	42/37
1	0	1	1	1	8.5	629	716	3.53	520	4	0	0.733	42/37*

* 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	$P_{g,F}$	$\Delta P_{g,F}$
N-SF66 923209.400	1.92286	20.88	0.044199	1.93322	20.70	0.045076	1.90368	1.91039	1.95739	1.98285		0.6394	0.0307
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	0.5983	0.0042
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	0.5886	0.0017
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	0.6036	0.0062
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	0.5919	0.0023
SF6[H] 805254.518	1.80518	25.43	0.031660	1.81265	25.24	0.032201	1.79117	1.79609	1.82970	1.84707	1.86436	0.6102	0.0092
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	0.6046	0.0085
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	0.6098	0.0098
SF57[H] 847238.551	1.84666	23.83	0.035536	1.85504	23.64	0.036166	1.83102	1.83650	1.87425	1.89393	1.91366	0.6160	0.0123

[H] Also available in HT or HHT quality.

CR	FR	SR	AR	PR	α (−30/+70)	T_g	$T_{10^{7.6}}$	ρ	HK	HG	B	τ_i (10/400)	FC
1	0	1	1	1	5.9	710	806	4.00	440	3	1	0.504	45/39*
2	1	3.2	2.3	3	8.1	417	566	4.46	390	1	1	0.967	39/34
1	0	2	2.3	2	8.4	441	600	3.86	410	2	0	0.981	37/33
1	2	4.3	2.3	3.3	8.0	420	552	4.79	390	1	1	0.954	40/35
1	1	2	2.3	3	8.2	425	580	4.07	410	2	1	0.980	37/33
2	3	51.3	2.3	3.3	8.1	423	538	5.18	370	1	0	0.915	42/36
1	0	1	1.2	2	7.5	454	595	4.28	430	1	0	0.862	41/37
1	1	3.2	2.2	3.2	7.9	429	556	4.92	380	1	1	0.857	42/37
2	5	52.3	2.3	4.3	8.3	414	519	5.51	350	1	0	0.847	40/37*

* 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	$P_{g,F}$	$\Delta P_{g,F}$
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	0.5419	–0.0111
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	0.5590	–0.0100
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	0.5710	–0.0060
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	0.5833	–0.0021
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	0.5605	–0.0120
KZFSN5[i] 654396.346	1.65412	39.63	0.016507	1.65803	39.40	0.016701	1.64644	1.64920	1.66668	1.67512	1.68319	0.5700	–0.0071
KZFS12[ii] 696363.384	1.69600	36.29	0.019179	1.70055	36.06	0.019425	1.68717	1.69033	1.71065	1.72059	1.73017	0.5778	–0.0050

[i] Will become inquiry glass as of 2011/01/01. For new designs please use N-KZFS5 instead of KZFSN5.

CR	FR	SR	AR	PR	α (−30/+70)	T_g	$T_{10^{7.6}}$	ρ	HK	HG	B	τ_i (10/400)	FC
1	4	52.3	4.3	4.2	4.4	491	600	2.55	490	3	1	0.985	34/30
1	1	3.4	1.2	1	7.3	536	675	3.00	520	3	1	0.979	36/32
1	0	1	1	1	6.4	584	739	3.04	555		1	0.976	37/32
1	0	1	1	1	7.8	509	635	3.20	570	4	1	0.963	38/33
1	1	3.4	1	1	6.6	551		3.20	530	3	1	0.987	36/30
3	2	52.3	4.3	4.3	4.5	501		3.46	460	5	1	0.976	37/34
4	1	53.3	4.3	4.3	5.2	492	549	3.84	440	4	1	0.919	40/35

[ii] Will become inquiry glass as of 2012/01/01. Not recommended for new design.

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	$P_{g,F}$	$\Delta P_{g,F}$
P-PK53[i] 527662.283	1.52690	66.22	0.007957	1.52880	65.92	0.008022	1.52309	1.52447	1.53288	1.53673	1.54029	0.5408	0.0084
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	0.5412	–0.0024
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	0.5671	–0.0079
P-SF67 907214.424	1.90680	21.40	0.042374	1.91675	21.23	0.043191	1.88833	1.89480	1.93985	1.96401		0.6334	0.0256
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	0.5991	0.0079
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	0.5290	0.0036
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	0.5359	0.0342
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	0.5377	0.0311
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	0.5401	0.0258
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	0.5419	–0.0111
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	0.5590	–0.0100

[i] Will become inquiry glass as of 2014/01/01. Not recommended for new design.

FR	SR	AR	PR	SR-J	WR-J	α (–30/70)	α (20/300)	T_g	AT	ρ	HK	B	τ_i (10/400)	FC
1	51	4.3	4.3	3	1	13.3	16.0	383	418	2.83	335	1	0.994	36/31
3	52.3	2	3	4	1	7.2	8.9	493	522	3.01	535	1	0.994	34/31
1	51.4	1	2.2	3	1	6.0	7.3	530	580	4.54	620	1	0.967	39/33
0	1	1.3	1	1	1	6.2	7.4	539	601	4.24	440	1	0.276	48/39*
0	1	1.2	1	1	1	9.4	11.1	524	580	2.90	533	1	0.924	40/36
1	4	2	2.3	5	4	9.2	10.0	466	557	2.45	520	1	0.998	30/27
0	52.3	2.2	4.3	3	1	12.7	14.8	464	503	3.68	345	1	0.997	34/28
0	52.3	3.3	4.3	4	1	13.0	15.0	467	520	3.70	355	1	0.997	34/28
0	52.3	3.3	4.3	3	1	12.4	14.1	487	528	3.86	415	1	0.994	34/29
4	52.3	4.3	4.2	6	6	4.4	5.4	491	533	2.55	490	1	0.985	34/30
1	3.4	1.2	1	6	4	7.3	8.2	536	597	3.00	520	1	0.979	36/32

* 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	$P_{g,F}$	$\Delta P_{g,F}$
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	0.5710	–0.0060
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	0.5833	–0.0021
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	0.5626	–0.0071
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	0.6160	0.0123

FR	SR	AR	PR	SR-J	WR-J	α (–30/70)	α (20/300)	T_g	AT	ρ	HK	B	τ_i (10/400)	FC
0	1	1	1	1	1	6.4	7.4	584	648	3.04	555	1	0.976	37/32
0	1	1	1	1	1	7.8	9.4	509	561	3.20	570	1	0.963	38/33
2	52.2	1	3	6	1	5.6	6.7	600	628	4.36	730	0	0.957	39/32
5	52.3	2.3	4.3	6	1	8.3	9.2	414	449	5.51	350	0	0.847	40/37*

* 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	$P_{g,F}$	$\Delta P_{g,F}$
LITHOSIL Q 458678.220	1.45844	67.83	0.006759	1.46005	67.68	0.006798	1.45512	1.45634	1.46348	1.46667	1.46959	0.5276	–0.0021

CR	FR	SR	AR	PR	α (−30/+70)	T_g	$T_{10}{}^{7.6}$	ρ	HK	HG	B	τ_i (10/400)	FC
1	0	1	1	1	0.5	980	1600	2.20	580		0	0.999	17/16

FS

Inquiry glasses
classical 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	$P_{g,F}$	$\Delta P_{g,F}$
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	0.5329	−0.0003
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	0.5474	−0.0005
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	0.5453	−0.0009
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	0.5669	0.0015
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	0.5625	0.0002
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	0.5603	−0.0028
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	0.6218	0.0177
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	0.6159	0.0148
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	0.6147	0.0142
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	0.5976	0.0095
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	0.5423	0.0053

CR	FR	SR	AR	PR	α (–30/+70)	T_g	$T_{10}7.6$	ρ	HK	HG	B	τ_i (10/400)	FC
2	3	52.4	2	1	8.2	362	622	2.27	380		1	0.994	33/30
3	3	52.2	2	2.2	6.8	633	758	3.64	550	3	1	0.988	36/32
3	3	52.2	2	3.2	6.7	641	752	3.62	620	3	1	0.984	36/31
1	0	1	1	1	7.2	583	714	2.79	560	2	1	0.959	39/35
2	0	2	2	1	7.8	549		3.17	540		1	0.971	38/33
2	3	52.3	1.2	3.3	7.6	646	740	4.14	580	5	1	0.954	39/34
1	0	1.3	1	1.3	8.7	598	700	3.55	580	3	1	0.525	44/38*
1	0	2	1	1	9.0	585		3.37	570		0	0.850	45/37
1	0	1	1.2	1	6.1	503	635	4.74	450	1	1	0.525	44/39
1	0	1	1.2	1	7.2	598	707	2.90	630	3	1	0.901	40/36
2	1	52.3	1.2	4.3	9.4	618	709	3.60	440	6	1	0.985	36/31

INQ

* 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	$P_{g,F}$	$\Delta P_{g,F}$
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	0.6028	0.0099
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	0.6139	0.0140
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	0.5982	0.0033
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	0.5376	0.0007
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	0.5803	0.0036
LF5G15 584408.322	1.58397	40.83	0.014301	1.58736	40.55	0.014484	1.57739	1.57974	1.59489	1.60228		0.5759	0.0008
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	0.5500	0.0017
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	0.5462	–0.0055
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	0.5831	0.0008
SF6G05 809253.520	1.80906	25.28	0.032015	1.81661	25.08	0.03257	1.79491	1.79988	1.83387			0.6121	0.0108

CR	FR	SR	AR	PR	α (−30/+70)	T_g	$T_{10^{7.6}}$	ρ	HK	HG	B	τ_i (10/400)	FC
1	0	1	1.2	1	8.5	572	685	2.99	620	4	1	0.850	42/37
1	0	1	1.3	1	8.7	592	691	3.28	560	5	1	0.799	44/37
1	0	1.3	1	1.3	7.4	774		5.41	810	1	2	0.634	45/37*
	0	1	2		7.0	585	722	2.52	580		0	0.764	41/37
2 – 3	2	3.4	2.2	3	10.7	474	606	3.30	410	2	1	0.276	45/39
2	0	1	1.3	2.3	9.3	407	578	3.22	446		1	0.569	43/37
	0	1	1		9.0	483	679	2.59	510		1	0.821	41/37
1 – 2	2	53.0	1.3	4.3	6.3	634	710	3.53	721		2	0.292	46/38
1	0	1	1.3	2.3	8.1	435	604	3.60	428		1	0.325	45/39
4	3	51.3	2.3	3.3	7.8	427	529	5.20	360		1		52/46*

* Wavelength for transmittance 0.7 and 0.05

Notes

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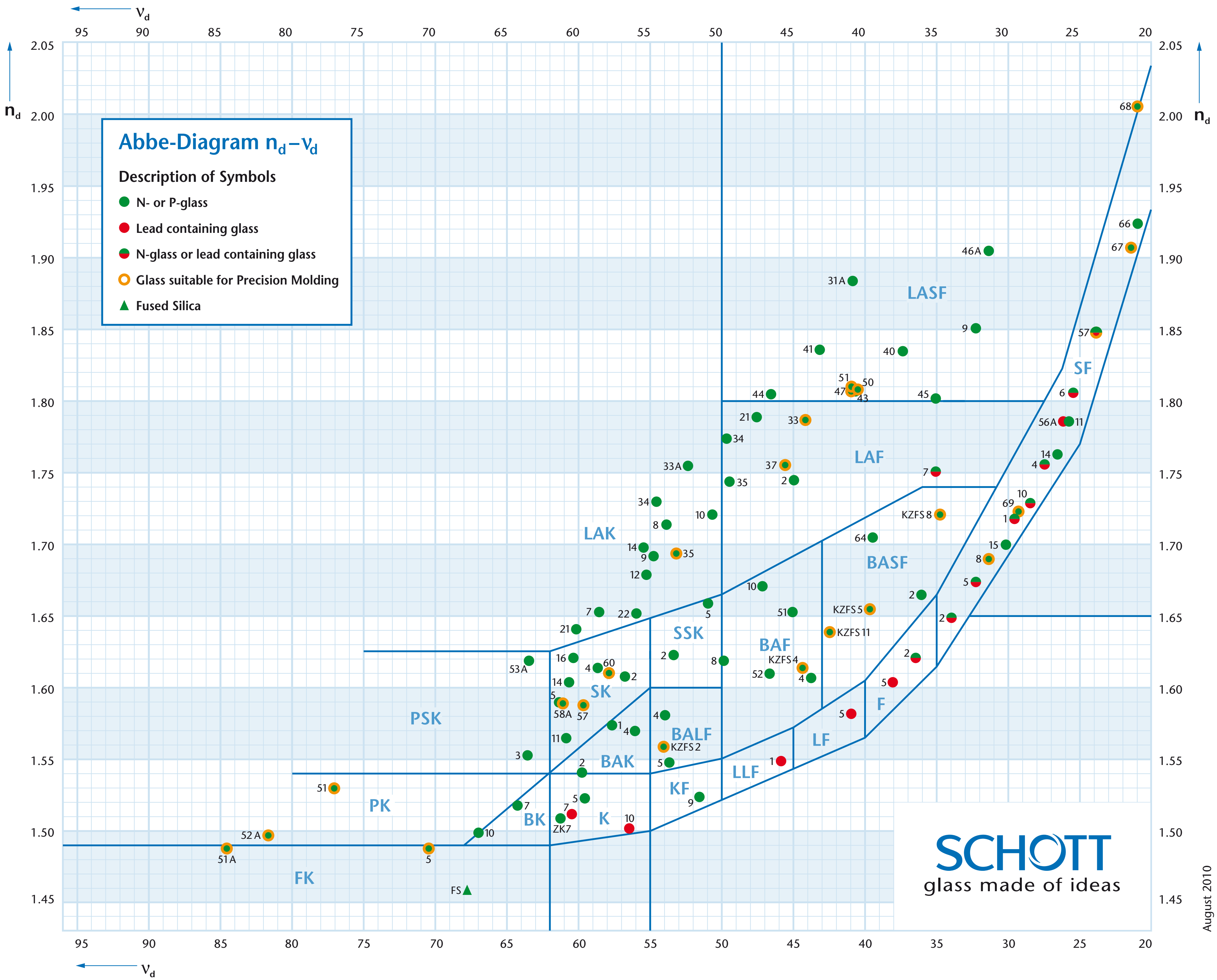
Abbe-Diagram $n_d - \nu_d$



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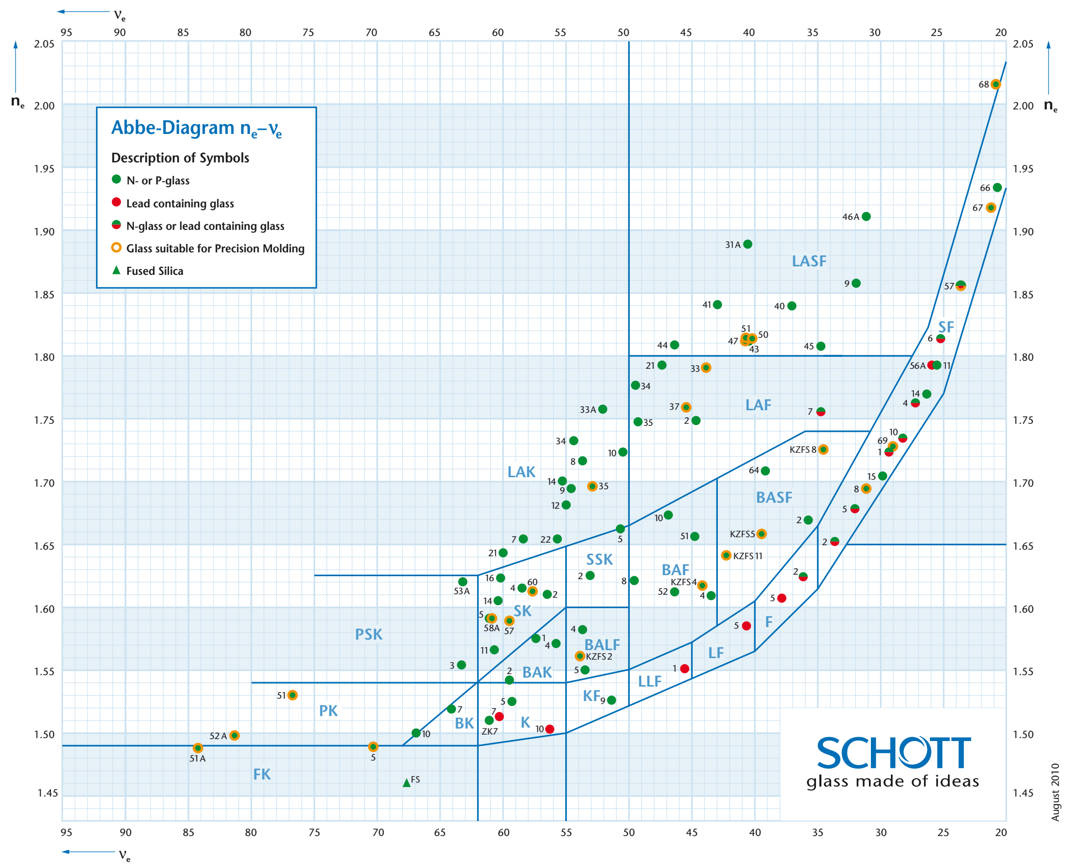
Abbe-Diagram $n_e - \nu_e$



$P_{g,F}$-Diagram