Technical Information
Advanced Optics

Version November 2020

TIE-35 Transmittance of optical glass

Introduction

Optical glasses are optimized to provide excellent transmittance throughout the total visible range from 380 to 780 nm (perception range of the human eye). Usually the transmittance range spreads also into the near UV and IR regions. As a general trend lowest refractive index glasses show high transmittance far down to short wavelengths in the UV. Going to higher index glasses the UV absorption edge moves closer to the visible range. For highest index glass and larger thickness the absorption edge already reaches into the visible range. This UV-edge shift with increasing refractive index is explained by the general theory of absorbing dielectric media. So it may not be overcome in general. However, due to improved melting technology high refractive index glasses are offered nowadays with better blue-violet transmittance than in the past. And for special applications where best transmittance is required SCHOTT offers improved quality grades like for SF57 the grade SF57HTultra.

The aim of this technical information is to give the optical designer a deeper understanding on the transmittance properties of optical glass.

---

1. Theoretical background

A light beam with the intensity I_0 falls onto a glass plate having a thickness d (figure 1). At the entrance surface part of the beam is reflected. Therefore after that the intensity of the beam is $I_{i0}=I_0(1-r)$ with r being the reflectivity. Inside the glass the light beam is attenuated according to the exponential function. At the exit surface the beam intensity is

$$I_i = I_{io}\, exp(-kd) \qquad (1.1)$$

where k is the absorption coefficient. At the exit surface another reflection occurs. The transmitted beam has the intensity $I=I_i(1-r)$. These formulas give the following relation:

$$I = I_o\, (1-r)^2\, exp(-kd) \qquad (1.2)$$

The beam reflected at the exit surface returns to the entrance surface and is divided into a transmitted and a reflected part. With multiple reflections taken into account, the transmittance of the glass plate is:

$$\tau = \frac{I}{I_o} = P\tau_i \qquad (1.3)$$

with

$$\tau_i = \frac{I_i}{I_{io}} = \text{internal transmittance} \qquad (1.4)$$

and

$$P \approx \frac{2n}{n^2+1} \qquad (1.5)$$

➜

TIE-35 Transmittance of optical glass

P is called the "reflection factor" and has been derived from Fresnel's formula which describes the relation between the reflectivity r and the refractive index n. The used formulae for P is an approximation under the assumption that the absorption of optical glass is usually small in the relevant visible spectral range. More details can be found in [1]. Taking the refractive index range of optical glass from 1.4 to 2.1 the reflection factor P ranges from 0.92 to 0.75.

The transmittance is thickness dependent. If the internal transmittance τ_{i1} of a plate with thickness d_1 is known, it is possible to calculate the internal transmittance τ_{i2} of a plate with a thickness d_2:

$$\tau_{i2} = \tau_{i1}^{(d_2/d_1)} \qquad (1.6)$$

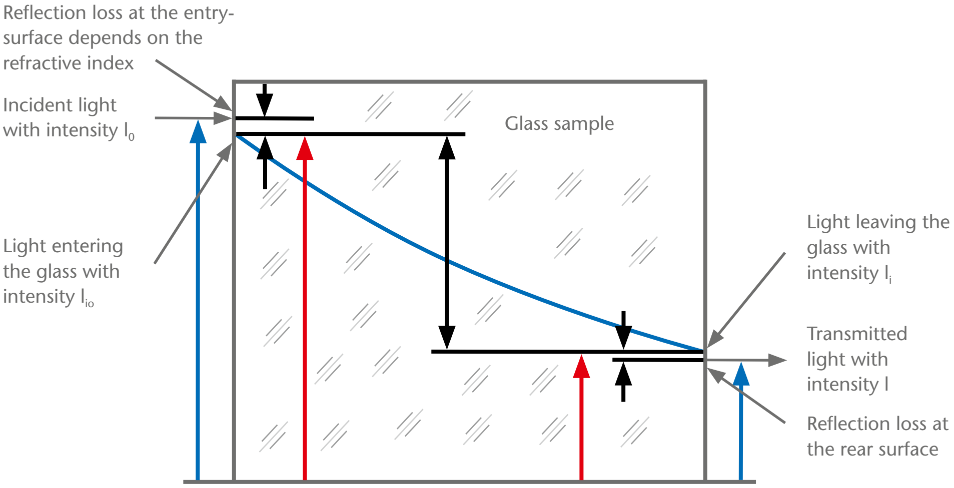

Fig. 1: Change in the intensity of a light beam passing through a glass plate [2].

2. Wavelength dependence of transmittance

The transmittance of an optical glass is inversely proportional to its spectral absorption. The absorption bands of a glass are closely related to its dispersion behavior.

The dispersion is a measure of the change of the refractive index with wavelength. Dispersion can be explained by applying the electromagnetic theory to the molecular structure of matter. If an electromagnetic wave impinges on an atom or a molecule the bound charges vibrate at the frequency of the incident wave.

The bound charges have resonance frequencies at certain wavelengths. A plot of the refractive index n as a function of the wavelength for fused silica can be seen in figure 2. In the main spectral transmittance region the refractive index increases towards shorter wavelength. The dotted line shows the absorption coefficient k as a function of the wavelength.

TIE-35 Transmittance of optical glass

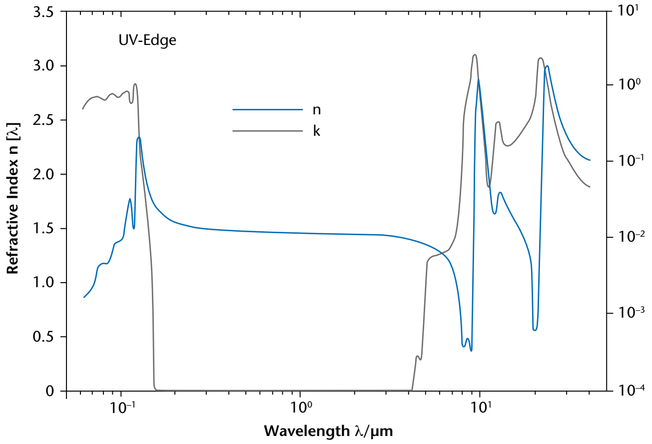

Fig. 2: Measured optical constants of fused silica (SiO_2 glass). The influence of the UV-edge on the refractive index is clearly visible [2].

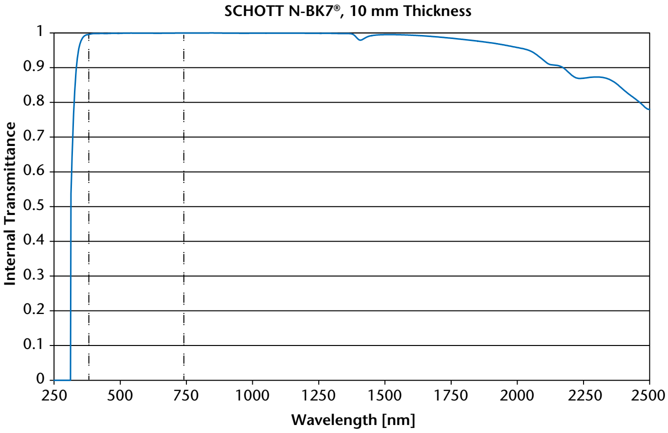

Fig. 3: Internal transmittance of SCHOTT N-BK7® at 10 mm thickness measured with 2 nm spacing. The dashed lines indicate the limits of the visible spectrum.

Regions of strong dispersion, with steep slopes in the refractive index curve, correspond to absorption bands, this can be clearly seen in figure 2. If for example the UV transmittance edge (short wavelength edge) of the glass is shifted to shorter wavelengths, meaning that the glass has a good transmittance in the blue and near UV region, the dispersion of the glass in the visible (the slope of the n(λ) curve) is very low. This is valid for low refractive index glasses. In high refractive index glasses the UV edge of the transmittance curve is shifted to longer wavelengths, therefore the refractive index in the visible is much higher and the slope (dispersion) much steeper. It is useful to note that the refractive index, dispersion and transmittance are tightly connected.

Figure 3 shows the internal transmittance of a typical SCHOTT N-BK7® sample. Between 400 nm and 1060 nm the internal transmittance is higher than 99% for a 25 mm thick sample. In the ultraviolet (UV) and infrared (IR) wavelength range (below 400 nm and over 1060 nm wavelength for SCHOTT N-BK7®) the transmittance decreases rapidly due to absorption effects.

2.1 UV transmittance

The UV Transmittance characteristic is mostly influenced by heavier elements in the glass composition (like e.g. lead, barium, niobium, titanium, lanthanum), melting technology and/or residual impurities. These heavier elements are necessary to achieve a high refractive index but decrease the transmittance in the blue region. Therefore high refractive index glasses in bigger thickness often show a yellowish color.

Nevertheless there are differences in the characteristic of the UV transmittance edge depending on which heavy elements are used in the glass composition. For example lead containing SF glasses exhibit a better transmittance in the blue spectral region compared to N-SF glass types were lead was substituted by titanium or niobium. The melting process also influences the transmittance characteristics of a glass, for example platinum parts in the melting tank could be the source for platinum impurities in the glass leading to a weaker UV transmittance. Modern melting techniques aiming for the reduction of platinum contact with the melt therefore lead to better transmittance characteristics.

TIE-35 Transmittance of optical glass

Therefore it is also possible that the transmission of the eco versions of a heavy flint (N-SF) exhibits a higher transmission than the lead-containing version in the blue area if the N-SF version is continuously produced in a tank, due to it's high demand in mass markets and its lead containing equivalence glass type has to be discontinuously produced in the pot, as it has been observed with N-SF14/SF14 and N-SF11/SF11. The simple rule that the eco version of a heavy flint always exhibits a lower transmission in the blue area is therefore only valid if both versions are continuously produced under similar conditions.

The UV transmittance edge does not only depend on the composition of the glass but also on the thickness. With an increasing thickness the transmittance edge is shifted to longer wavelengths. Figure 4 shows a comparison of the internal transmittance near the UV edge between different refractive indices, different composition and material thickness.

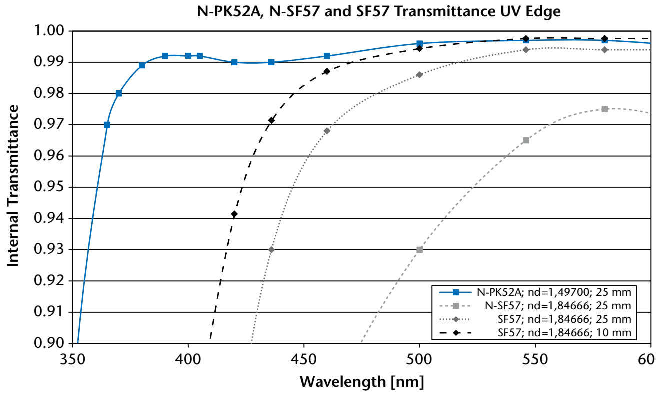

Fig. 4: Catalog internal transmittance data of N-PK52A, N-SF57 and SF57 in different thickness.

It should also be noted that increasing temperatures slightly shift the UV edge to longer wavelengths due to broadening of the UV absorption bands.

The UV transmission is important for microlithography applications. Optical glasses with excellent homogeneity and transmittance at 365 nm are for example FK5HTi, LLF1HTi and LF5HTi with transmittance >99% at 10 mm thickness.

2.2 Infrared transmittance

The transmittance of optical glasses is in general high in the visible and at wavelengths up to 1970 nm. The infrared transmittance is influenced by the OH content in the glass. A first small absorption usually can be found at 1450 nm. The main OH absorption band is sensitive to the atomic surrounding and typically occurs between 2.9 µm and 4.2 µm. Figure 5 shows the infrared internal transmittance of SCHOTT N-BK7® as an example. The sudden decreases in the transmission indicate absorption bands. The standard transmittance data in the optical glass datasheets covers only a five wavelengths above 700 nm: 1060 nm, 1530 nm, 1970 nm, 2325 nm and 2500 nm. The short wave infrared (SWIR) spectral band is located between the visible and the thermal infrared. Based on the existing data all SCHOTT optical glasses can be used in the 0.9 to 1.7 µm SWIR spectral range. Regarding a definition of the SWIR range up to 3 to 4 µm, most of the optical glasses have a low transmittance above 2 µm. Nevertheless, fluorophosphate optical glasses offer excellent transmittance even up to 4 µm [3].

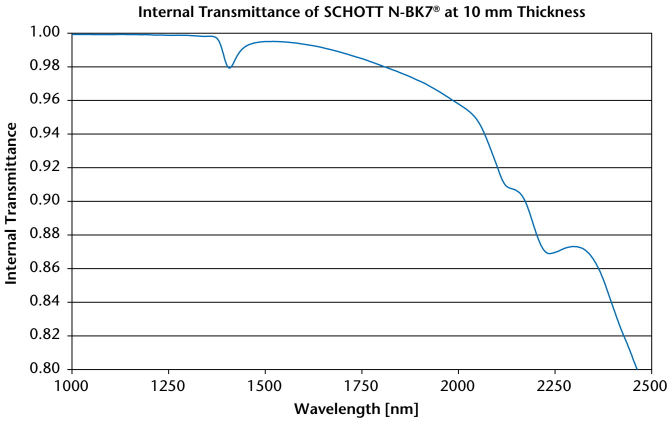

Fig. 5: Infrared internal transmittance curve of SCHOTT N-BK7®

Back to index

TIE-35 Transmittance of optical glass

Figure 6 shows high resolution transmittance measurements of N-FK51A, N-PK52A, N-BK10, N-FK58 XLD and N-PK51 at 2 mm sample thickness in the spectral range from 2.5 µm to 7.5 µm. The transmittance of the N-BK10 strongly degrades beyond 2.5 µm reflecting the usual behaviour of optical glass in the IR range. Nevertheless, it might be surprising to find that the fluoro-phosphate glass types show a much wider transmittance range in the IR up to 4 µm. The N-FK58 XLD shows the highest transmittance among the tested glasses.

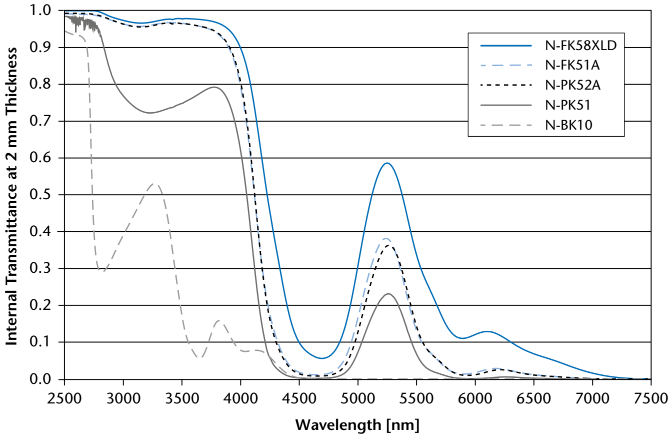

Fig. 6: Internal Transmittance of N-FK58XLD, N-PK51, N-FK51A, N-PK52A and N-BK10 in comparison at 2 mm thickness

The infrared transmittance is very sensitive to different melting techniques. The IR transmittance in the datasheet reflects typical values that might not be achieved always. Please tell your SCHOTT sales contact person in advance if special transmittance characteristics in the infrared region are relevant for your product.

2.3 Solarization

Electromagnetic radiation influences the transmittance of a glass depending on glass type and the wavelength of radiation. The influence of visible and UV radiation (less than 380 nm wavelength) on glass is called solarization. The UV radiation generates color-centers in the glass leading to a reduced transmittance. The solarization behavior of optical glass can be investigated by irradiation with a xenon or mercury lamp, or with UV lasers.

Glasses with low UV transmittance – e.g. with a high lead content (F and SF types) – normally have small solarization effects. Several crown glasses with a higher ultraviolet transmittance change their UV-transmittance edge: PSK, BK, K, ZK, BAK, SK and LaK. The steepness of the transmittance edge becomes smaller. This effect can be reversed at higher temperatures (the higher the temperature the faster the effect will be reversed).

Figure 7 shows the solarization behavior of several optical glasses. The samples were irradiated with an UV lamp (HOK Hg lamp, maximum at 365 nm) for about 15 hours at a distance of 7 cm. The diagram on top of figure 7 shows the transmittance before irradiation measured at 10 mm thickness. The diagram on the bottom of figure 7 shows the transmittance loss as a function of wavelength for the 5 glasses displayed.

The transmittance loss is highest at shorter wavelength. SCHOTT N-BK7® shows a transmittance loss of maximum 5 % around 320 nm. FK5HTi has a transmittance loss of less than 2 % with a maximum at smaller wavelength reflecting the better UV transmittance. N-FK58 XLD very surprisingly shows extremely low transmittance loss of less than 0.5 % over the complete spectrum with almost no effect above the measurement noise.

The high refractive index glasses N-SF8 and N-LASF44 in figure 7 show lower absolute transmission losses. The maximum is around 1.5 % for N-LASF44. N-SF8 shows almost no transmittance loss. It is worth noting that the transmission loss of N-LASF44 covers a much broader wavelength range up to 800 nm in comparison to the other glasses. More curves can be found in [4].

Paper [4] also discusses solarization experiments with femtosecond laser irradiation. These experiments were done at the Laser Zentrum Hannover using a titanium-sapphire solid state laser with 150 fs pulses at a wavelength of 387.5 nm and 1 kHz repetition rate. Several optical glasses from SCHOTT were irradiated with increasing power density from 0.15 W/mm² to 19.56 mW/mm². N-FK58XLD showed a very high stability (figure 8).

Back to index

TIE-35 Transmittance of optical glass

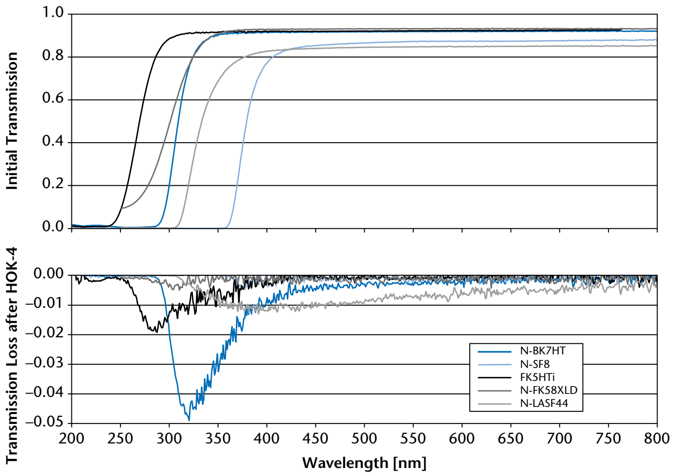

Fig. 7: Solarization behavior of selected low and high refractive index glasses irradiated with a HOK lamp for 15 hours. Selected results from [4].

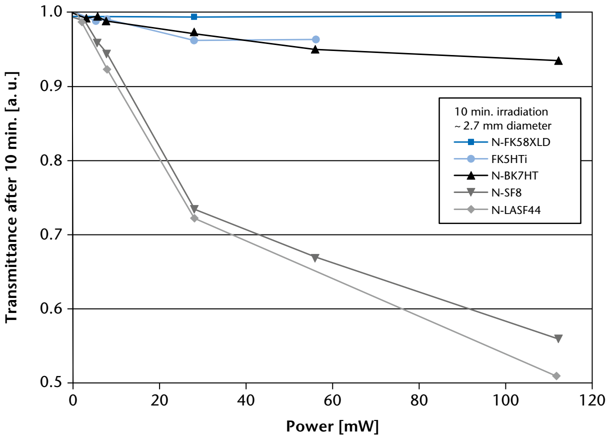

Fig. 8: Solarization behavior of selected low and high refractive index glasses irradiated with a titanium-sapphire fs laser at 387.5 nm for 10 minutes. Selected results from [4].

The influence of UV radiation can be partly suppressed by doping the glass with CeO_2. The doping stabilizes the UV-transmittance edge but also shifts it to longer wavelengths. Therefore this way of stabilization is usually not very common to stabilize optical glass against UV radiation. Other stabilization methods with less impact on the UV edge are usually preferred. In the case of irradiation with sources of higher quantum energies (X-rays, γ-rays) CeO_2 doping proves protective. In the case of neutron and electron radiation the protective effect of CeO_2 doping depends on the glass type. Therefore the radiation load to which the glass will be exposed must be considered when choosing a certain optical glass.

CeO_2 doped glasses are indicated with a G plus number behind the glass name. Typical examples are: BK7G18, K5G20, LAK9G15, LF5G19 and SF6G05. More information can be found in technical information TIE-42 [5].

Back to index

TIE-35 Transmittance of optical glass

3. Measurement and specification

3.1 Transmittance measurement setup

The transmittance of optical glass is measured using double beam spectral photometers from the company Perkin Elmer with special modifications.

The standard setup enables to measure within a wavelength region from 250 nm up to 2500 nm. The measurement accuracy over the complete spectrum is about ±0.5 %. Within 400 nm to 700 nm the accuracy is ±0.3 %. The wavelength can be measured with an accuracy of ±0.2 nm and ±0.8 nm. Standard measurement sample thickness is 25 mm (20 mm x 15 mm x 25 mm).

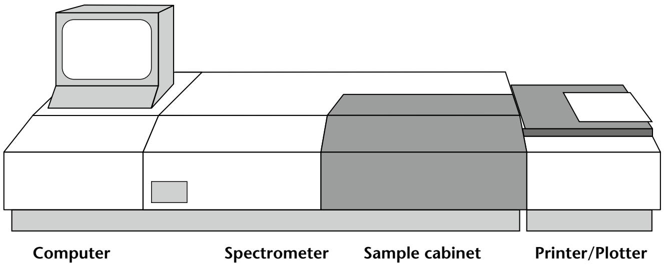

Fig. 9: Spectral photometer from Perkin-Elmer

With an improved setup it is possible to increase the transmittance measurement accuracy in the UV and visible range (200 – 850 nm) to ±0.08 % and in the near infrared range (850 – 2500 nm) to ±0.3 % (with ±0.02 nm in the UV/VIS and ±0.08 nm in the NIR). Additionally it is possible to expand the wavelength range from 2500 nm to 16600 nm. Within this range the measurement accuracy is ±1 %.

3.2 Transmittance specification

SCHOTT attempts to achieve the best possible internal transmittance. However, due to cost and availability constraints, some deviations in the purity of the raw materials must be accepted. SCHOTT maintains minimum standards for the resulting deviations in internal transmission of melted glasses.

The spectral transmittance of the optical glasses for 10 mm and 25 mm thickness are listed in the data sheets. The transmittance data given in the data sheets comprises median values from several melts of a glass type in general expect for HT or HTultra (refer to chapter 3.3). Upon request minimum values for internal transmittance can be maintained. It should also be addressed in advance if special transmission characteristics in the infrared region are crucial for the application. Prior clarification of the delivery situation is required.

3.3 Color code and UV cut of edge

The color code is a description of the position and slope of the UV transmittance edge. The color code lists the wavelength λ_{80} and λ_5, at which the transmittance (including reflection losses) is 0.8 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 λ_{80} = 330 nm and λ_5 = 300 nm. For high index glass types with nd > 1.83 the data of the color codes refer to the transmittance values 0.70 and 0.05 (λ_{70} and λ_5) because of the high reflection loss of this glass (refer to figure 10).

The color code given in the data sheets should be regarded as a median value. Upon request minimum values for internal transmittance can be maintained. Prior clarification of the delivery situation is required. The color code is also represented in the ISO12123:2018 [6].

Back to index

TIE-35 Transmittance of optical glass

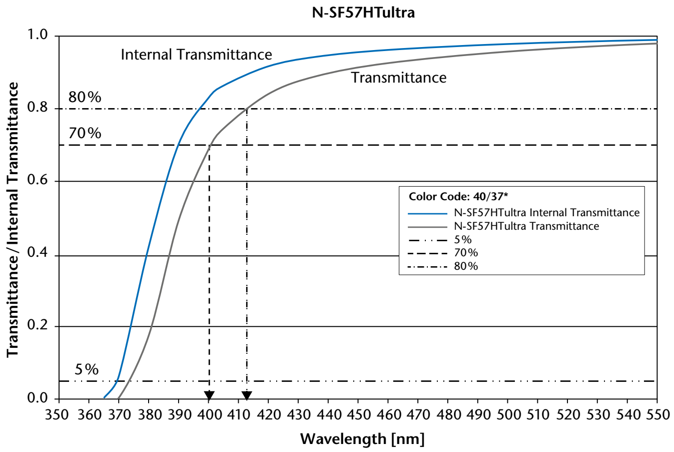

Fig. 10: Color code definition for high index glass types

Additionally the UV cut-off edge is defined since the version 2018 of ISO 12123. In contrast to the color code the UV cut-off edge lists the wavelengths wavelength λ_{80} and λ_{10}.

In which the spectral internal transmittance (excluding reflection losses) is 0,8 and 0,1 at 10 mm thickness. The reflection loss can be calculated from the datasheet refractive index data for each wavelength.

3.4 HT and HTultra quality

Some glasses are offered in HT or HTultra quality (e.g. SF6, SF57 but also F2 and the I-Line glasses FK5, LLF1 and LF5). The internal transmittance of these glasses (absolute and color codes) exceeds the quality of the normal type especially in the visible range. Applications of high refractive index glasses strongly benefit from the improved transmittance at the UV edge. The HT and HTultra transmittance values given in the datasheets can be regarded as guaranteed minimum values in the visible spectral range. Figure 11 shows a comparison of SF57, SF57HTultra, N-SF57 and N-SF57HTultra.

The benefits of HT glasses are for example reduced thermal lensing in prims setups with long optical path lengths of digital projection applications, improved transmittance and color appearance in complex telezoom lens systems and better mesopic vision of binoculars.

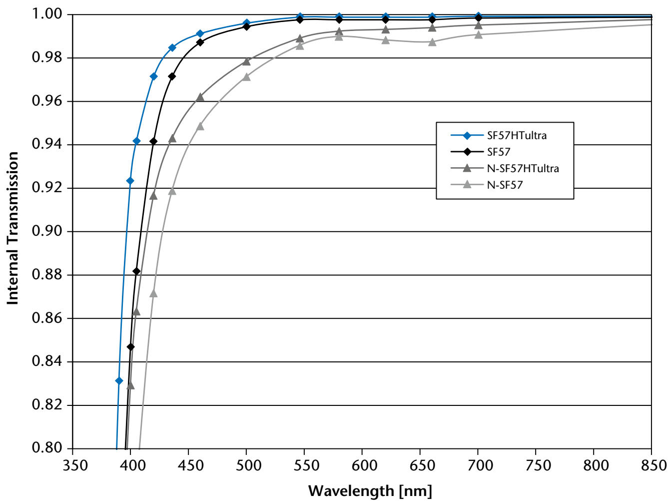

Fig. 11: Comparison of SF57, N-SF57 and their HTultra variations

The following glasses are available in HT or HTultra quality:

FK5HTi	F2HT	N-SF57HT
LF5HTi	N-BAK4HT	N-SF57HTultra
LLF1HTi	N-BK7HT	N-SF6HT
N-BK7HTi	N-KZFS4HT*	N-SF6HTultra
	N-LASF45HT*	N-SK2HT
	N-LASF9HT*	

*will become inquiry glass as of 01/2022

Back to index

TIE-35 Transmittance of optical glass

4. Literature

[1] F.J.P. Soler, Multiple reflections in an approximately parallel plate; Optics Communications 139 (1997) 165-169

[2] The properties of optical glass; H. Bach & N. Neuroth (Editors), Springer Verlag 1998

[3] From VIS to SWIR: a challenge for optical glass and IR materials; R. Jedamzik, U. Petzold, G. Weber, Proc SPIE 10528, 2018

[4] Latest results on solarization of optical glasses with pulsed laser radiation; R. Jedamzik, U. Petzold, SPIE Proc. 10097 (2017)

[5] Radiation resistant optical glass; Technical Information TIE-42, 2018

[6] ISO 12123:2018 Optics and photonics – Specification of raw optical glass

Version November 2020 | SCHOTT Advanced Optics reserves the right to make specification changes in this product flyer without notice.

← Back to index