1. Optical materials

1.1. Optical glasses

1.1.1. Standard optical glasses

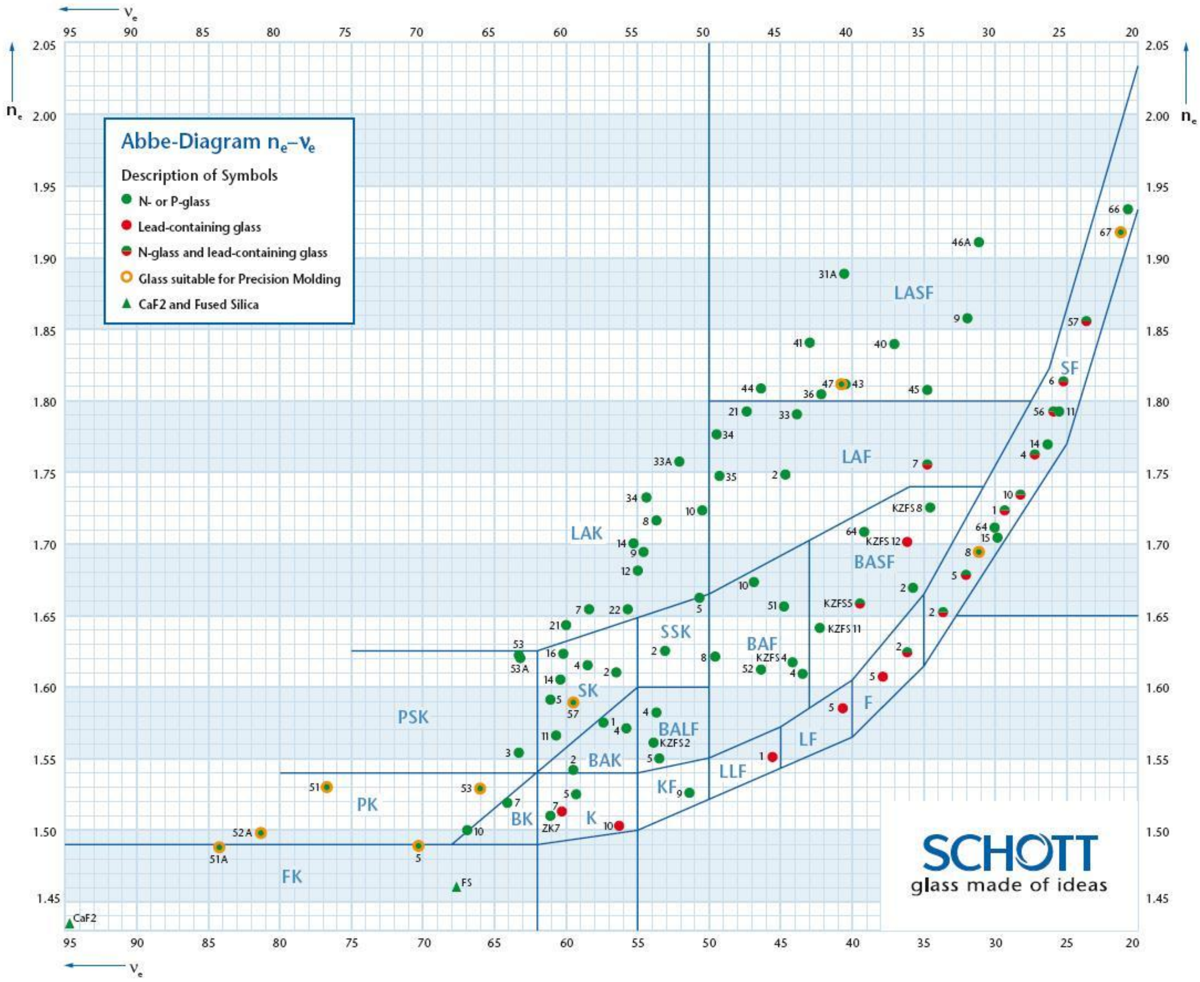
Optical glasses are inorganic products in molten form and with homogeneous and amorphous structure, without impurities and strains. The most important parameters of these glasses are: index of refraction and the Abbe number describing the dispersion (rate of change of index with wavelength). Standard optic al glasses are a group of glasses characterized by maximum transmission in the visible spectral range.

These glasses are classified into two basic groups:

- ❑ crown glasses ($\nu_e > 55$), are weakly refractive (around 1.5 - 1.6) and have low dispersion.
- ❑ flint glasses ($\nu_e < 50$), contained of lead oxygen, and have higher index of refraction (1.7 - 1.9), and stronger dispersion.

There are a few intermediate groups between the two mentioned above.

As standard we use glasses from Schott and Ohara but on request we can produce components from glasses of other producers as well.



1.1.2. Special optical glasses

Special optical glasses are optimized from the point of view of precise requirements of optical properties, and generally have individual, dominate characteristics, which differs them from standard glasses with ordinary parameters.

Borosilicate glass is a type of glass with the main glass-forming constituents silica and boron oxide. Borosilicate glasses are most well known for having very low coefficient of thermal expansion (~5×10^{-6} /°C at 20°C), making them resistant to thermal shock, more so than any other common glass. Main applications for this material are mirror substrates and optical windows.

Borofloat®33 is a particular SCHOTT Borosilicate Glass. It is characterized by excellent flatness and better resistance to heat. The name Borofloat is a combination of borosilicate glass and the float glass technology.

Pyrex® is a CORNING Borosilicate Glass. It is like Borofloat well suited for applications in which high temperature or thermal shock are primary considerations

Crown glass is type of optical glass used for optical components. It has low refractive index (≈1.52) and low dispersion (with Abbe numbers around 60). The SCHOTT crown glass **B270 Superwite®**, manufactured by Up-Draw-Technology, offers high stability with respect to solarisation, high transmittance in the visible wavelength range and high thermal and chemical stability. The glass has a fire-polished surface. It is typically used as mirror substrate. The Coefficient of expansion α (20 °C; 300 °C) in 10^{-6} /°C is 9.4

1.1.3. Color filter glasses

Filter glasses change the spectral properties of optical radiation by selective absorption in optical spectral range above 200 nm up to 5200 nm.
Selecting proper material it is possible to produce different kinds of filters:
Bandpass filters which selectively transmit the desired region
Longpass filters which block undesired, shorter wavelengths,
Shortpass filters which block undesired, longer wavelengths, and
Neutral density and conversion filters which exhibit more or less non-selective attenuation in certain regions.

Our filters are produced with the use of glasses from all SCHOTT groups:
UG black and blue glasses, ultraviolet transmitting
BG blue, blue-green and multi-band glasses
VG green glasses
GG nearly colorless to yellow glasses, IR transmitting
OG orange glasses, IR transmitting
RG red and black glasses, IR-transmitting
NG neutral density glasses with uniform attenuation In the visible range
N-WG colorless glasses with different cutoffs in the UV, transmitting in the visible and the IR
KG virtually colorless glasses with high transmission in the visible and effective absorption in the IR (heat protection filters)

1.2. Glass ceramics

Glass-ceramic is an inorganic, non-porous material having crystalline and glass phases together. Such material structure grants glass ceramics its extraordinary properties, and makes it an ideal material for very special tasks, which call for the highest precision. Mainly it is used for production of large mirror substrates (for astronomy) or very small and light ones (for gyroscopes). Glass ceramics has unusual thermal stability.

Zerodur is a glass-ceramic made by Schott AG.
The most important properties of Zerodur are:

- Nearly zero thermal expansion (~0.2 x 10^{-7}/K at 0-50°C) with outstanding 3D homogeneity
- High internal quality
- Can be polished to a very high accuracy
- Can be coated easily
- Good chemical stability

CLEARCERAM-Z is a glass-ceramic produced by OHARA. Te HS version has also an expansion coefficient of (~0.2 x 10^{-7}/K at 0-50°C).

ULE®, Corning Code 7972 Ultra Low Expansion Glass is a titania silicate glass with unique characteristics that has made it the material of choice in applications for the space industry in maintaining the critical performance of optical systems at extreme temperatures. ULE is used in a broad array of applications from machine tool reference blocks to solid and lightweight mirror blanks for larger astronomical telescopes and space satellite applications.

1.3. Synthetic Fused Silica / Fused quartz glass

Fused quartz and **fused silica** are types of glass containing primarily silica in amorphous (non-crystalline) form.

Fused quartz is manufactured by melting naturally occurring quartz crystals of high purity at approximately 2000°C, using either an electrically heated furnace (electrically fused) or a gas/oxygen-fuelled furnace (flame fused). Fused quartz is normally transparent.

Synthetic fused silica is made from a silicon-rich chemical precursor usually using a continuous flame hydrolysis process which involves chemical gasification of silicon, oxidation of this gas to silicon dioxide, and thermal fusion of the resulting dust (although there are alternative processes). This results in a transparent glass with an ultra-high purity and improved optical transmission in the deep ultraviolet.

Fused silica is characterized by good transmission from UV by VIS up to NIR. It has very low thermal expansion index, and is very resistive for the most of chemical compounds. Another advantage its high damage threshold and very high melting temperature, which gives possibility of use in 1200°C.

Production of our components is generally based on synthetic fused silica or fused quartz from Heraeus (Suprasil, Homosil, Herasil, Infrasil) and Corning (HPFS7980)

Main properties of fused silica:

• High purity level
• Low OH Content
• High homogeneity
• Low thermal expansion
• High chemical resistance
• Excellent thermal shock resistance
• Low dielectric losses
• Low bubble content
• High optical transmission in the IR & UV
• Low thermal conductivity
• High use temperatures

1.4. Optical Crystals

A **crystal** or crystalline solid is a solid material whose constituent atoms, molecules, or ions are arranged in an orderly repeating pattern extending in all three spatial dimensions. A **single crystal** usually refers to a grain boundary free **monocrystaline** solid. **Polycrystalline** materials are solids that are composed of many crystallites of varying size and orientation. The variation in direction can be random (called random texture) or directed, possibly due to growth and processing conditions. Polycrystalline is the structure of a solid material that, when cooled, form crystallite grains at different points within it. Where these crystallite grains meet is known as grain boundaries, which can have significant effects on the physical and electrical properties of a material.

The table below shows a selection of crystalline materials used in our production. The values of the refractive index are for orientation only. These values differ slightly for the different manufacturers. The usable transmission range depends as well from the total conditions of the optical system.

Crystal	Formula	Density	Melting temperature	Transmission Range	Refraction Index
Lithium Fluoride	LiF	2,64 gcm^{-3}	870°C	0,12 - 8,5 µm	0,5 µm - 1,39 5,0 µm - 1,33
Calcium Fluoride	CaF_2	3,18 gcm^{-3}	1418°C	0,15 - 9,0 mm	0,5 µm - 1,44 5,0 µm - 1,40 10,0 mm - 1,30
Barium Fluoride	BaF_2	4,89 gcm^{-3}	1354°C	0,18 - 12µm	0,5 µm - 1,48 5,0 µm - 1,45 10,0 µm - 1,40
Magnesium Fluoride	MgF_2	3,18 gcm^{-3}	1255°C	0,13 - 7,0 µm	0,5 µm - 1,38 5,0 µm - 1,34
Quarz	SiO_2	2,64 gcm^{-3}	1740°C	0,4 - 4,5 µm	0,5 µm - 1,55 5,0 µm - 1,42
Sapphire	Al_2O_3	3,98 gcm^{-3}	2053°C	0,17 - 5,0 µm	0,5 µm - 1,77 1,0 µm - 1,75
Calcite	$CaCO_3$	2,71 gcm^{-3}	1339°C	0,22 - 3,0 µm	0,5 µm - 1,66 1,0 µm - 1,64
Zinc Selenide	ZnSe	5,26 gcm^{-3}	1520°C	0,55 - 18 µm	1,0 µm - 2,49 5,0 µm - 2,43 10,0 µm - 2,41
Zinc Sulfide	ZnS	4,09 gcm^{-3}	1827°C	1,8 - 12,5 µm	1,0 µm - 2,30 5,0 µm - 2,24 10,0 µm - 2,20
Germanium	Ge	5,33 gcm^{-3}	936°C	1,8 – 23 µm	2,0 µm - 4,10 5,0 µm - 4,02 10,0 µm - 4,00
Silicon	Si	2,33 gcm^{-3}	1420°C	1,2 - 15 µm	2,0 µm - 3,45 5,0 µm - 3,43
Lithium Niobate	$LiNbO_3$	4,64 gcm^{-3}	1530°C	0,35 – 5,5 µm	For λ 1,064 µm: n_o=2.22 n_e=2.15
KDP	KH_2PO_4	2,33 gcm^{-3}		0,18 – 1,5 µm	For λ 1,064 µm: n_o=1.49 n_e=1.46
DKDP	KD_2PO_4	2,35 gcm^{-3}		0,2 – 2,0 µm	For λ 1,064 µm: n_o=1.49 n_e=1.46
KTP	$KTiOPO_4$	3,01 gcm^{-3}	1150°C	0,35 – 4,5 µm	For λ 1,064 µm: n_x=1.74 n_y=1.75 n_z=1.83