Synthetic Fused Silica

Fused silica is an ideal optical material for many applications. It is transparent over a wide spectral range, has a low coefficient of thermal expansion, and is resistant to scratching and thermal shock.

Synthetic fused silica (amorphous silicon dioxide) is formed by chemical combination of silicon and oxygen. It is not to be confused with fused quartz, which is made by crushing and melting natural crystals, or by fusing silica sand, which results in a granular microstructure and bubble entrapment. Microstructure and impurities lead to local index variations and contribute, along with bubbles and opaque particles, to reduced transmission throughout the spectrum.

Synthetic fused silica is far purer than fused quartz. This increased purity ensures higher ultraviolet transmission and freedom from striae or inclusions. The synthetic fused-silica materials used by Melles Griot are manufactured by flame hydrolysis to extremely high standards. The resultant material is colorless and non-crystalline, and it has an impurity content of only about one part per million. Controlling the purity of reactants and the conditions of reaction ensures the high quality of the synthetic fused silica from which our lenses are made.

Synthetic fused-silica lenses offer a number of advantages over glass or fused quartz:

- Greater ultraviolet and infrared transmission
- Low coefficient of thermal expansion, which provides stability and resistance to thermal shock over large temperature excursions
- Wider thermal operating range
- Increased hardness and resistance to scratching
- Much higher resistance to radiation darkening from ultraviolet, X-rays, gamma rays, and neutrons.

Optical-quality synthetic fused silica (OQSFS) lenses are ideally suited for applications in energy-gathering and imaging systems in the mid-ultraviolet, visible, and near-infrared spectral regions. The low dispersion of fused silica reduces chromatic aberration.

UV-grade synthetic fused silica (UVGSFS) is selected to offer the highest transmission (especially in the deep ultraviolet) and very low fluorescence levels (approximately 0.1% that of fused natural quartz excited at 254 nm). UV-grade synthetic fused silica does not fluoresce in response to wavelengths longer than 290 nm. In deep ultraviolet applications, UV-grade synthetic fused silica is an ideal choice. Its tight index tolerance ensures highly predictable lens specifications.

The left-hand table on page 4.13 shows the refractive index of a typical UV-grade synthetic fused silica versus wavelength at 20ºC. To obtain the index for optical-quality synthetic fused silica, round the values off to the fourth decimal place.

Glass transmittances are affected by thermal history after manufacture, as well as during the manufacturing process. Depending on the manufacturer and subsequent thermal processing (coating, annealing, or tempering), it is possible for any optical glass, including BK7, to show internal transmittance reductions of several percent across the entire spectrum with external transmittance correspondingly affected. Transmittance of all glass is especially uncertain at wavelengths approaching the water absorption band at 2.7 μm.

Synthetic fused silica also shows batch-to-batch transmittance variations, especially in deep ultraviolet and infrared. These variations are related to manufacture and impurity content rather than subsequent history. In the ultraviolet, these variations have been attributed to uncontrollable fluctuations in metallic impurity content at the parts per billion level. Ultraviolet transmittance is the basis for the classifications UV grade and optical quality. A specification of UV grade ensures that a specimen is represented by the broadest curve. Transmittance curves for optical quality may fall anywhere between the UVGSFS curve and the OQSFS curve shown in figure 4.1.

Infrared batch-to-batch transmittance variations in synthetic fused silica are attributable to fluctuations in the OH chemical bond content. These variations are most pronounced at wavelengths near and beyond the water absorption band at 2.7 μm and are normally uncontrolled because ultraviolet transmittance is generally regarded as more important. High infrared transmittance can be ensured by appropriate manufacturing controls, but only at the sacrifice of ultraviolet transmittance.

Visible spectrum batch-to-batch transmittance variations in synthetic fused silica are insignificant. The high ultraviolet internal transmittance of UV-grade synthetic fused silica is correlated with a visible internal transmittance that is so high it is beyond traditional methods of measurement. It is necessary to measure optical signal attenuation in fibers drawn of the material.

Figure 4.2 shows a semilogarithmic comparison of the internal transmittances of UV-grade synthetic fused silica and BK7 glass. It is evident from this graph that UV-grade synthetic fused silica averages about two orders of magnitude less absorption loss than BK7 across the visible spectrum. In a sample thickness of 10 mm, the internal transmittance of UV-grade synthetic fused silica differs from unity only in the fifth decimal place. The high internal transmittance of such a material can be exploited by maintaining the optic at Brewster's angle for the appropriate linear polarization, or with the assistance of high-efficiency antireflection coatings such as HEBBAR™ or one of the laser line V-coats. With these coatings it is possible to achieve external transmittances of 98.5% and 99.5%, respectively. Synthetic fused silica and HEBBAR are especially well suited to each other in visible spectrum applications.

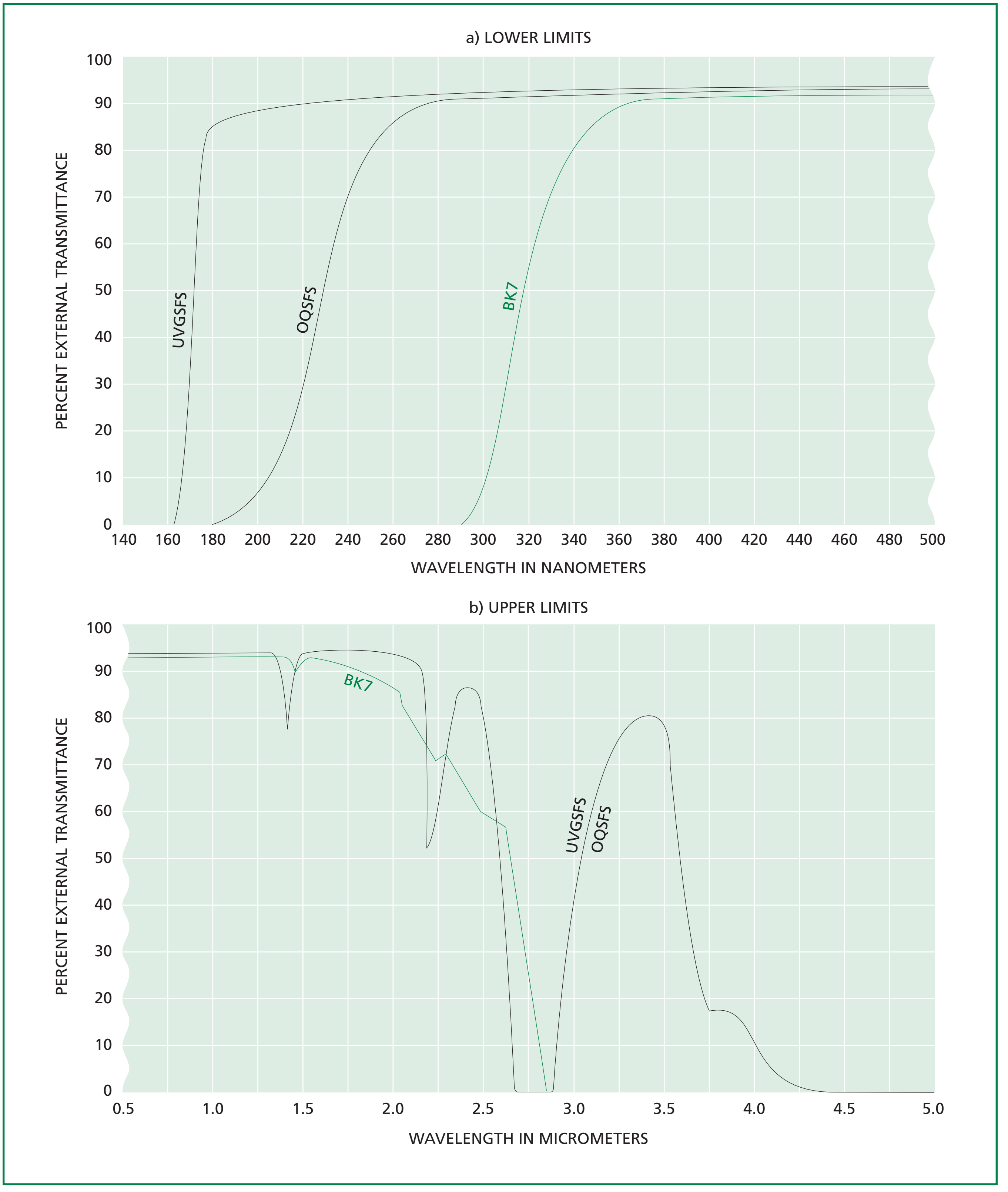

Figure 4.1 **Comparison of uncoated external transmittances for UVGSFS, OQSFS, and BK7, all 10 mm in thickness**

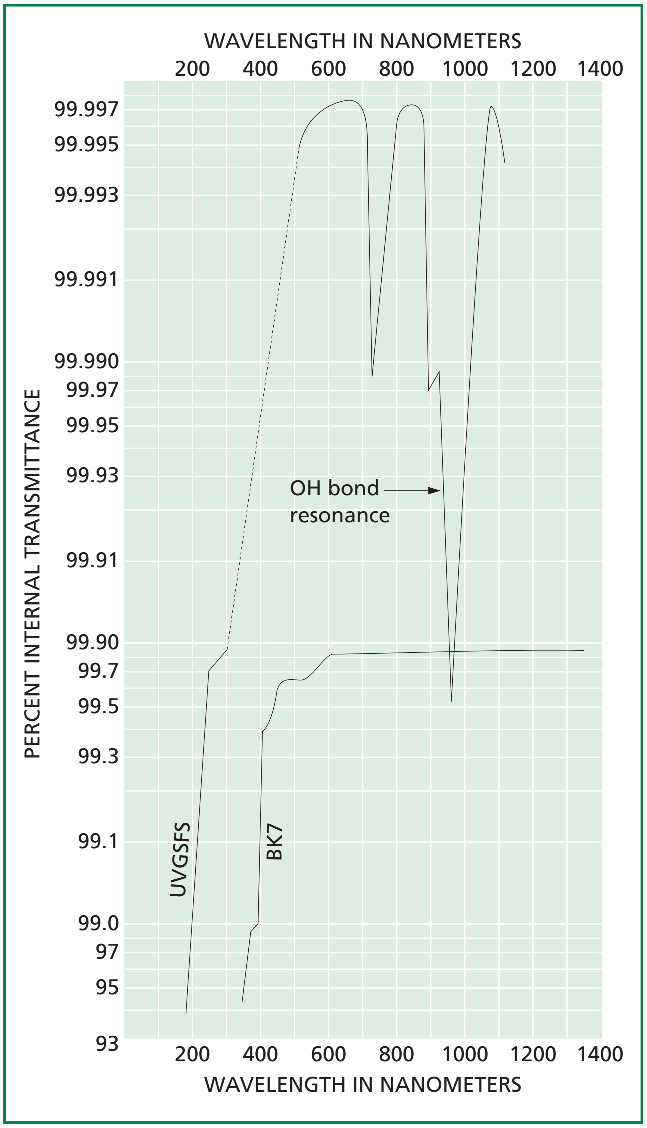

Figure 4.2 **Semilogarithmic comparison of internal transmittances of UVGSFS and BK7**

The internal transmittance of UV-grade synthetic fused silica shows a pronounced dip at 950 nm, while the data for BK7 give no hint of a corresponding feature. It should be understood that BK7 and UVGSFS are manufactured by very different processes. One of the many differences in these materials is that UVGSFS has a much higher content of OH chemical bonds (hydroxyl content) than does BK7. The dip in UVGSFS transmittance corresponds to the OH bond resonance.

SYNTHETIC FUSED-SILICA CONSTANTS

Abbé Constant: 67.8 ± 0.5

Change of Refractive Index with Temperature (0° to 700°C): 1.28×10^{-5}/°C

Homogeneity (maximum index variation over 10-cm aperture): 2×10^{-5}

Density (at 25°C): 2.20 g/cc

Continuous Operating Temperature: Maximum 900°C

Coefficient of Thermal Expansion: 5.5×10^{-7}/°C

Specific Heat (25°C): 0.177 cal/g°C

Dispersion Formula[1] at 20°C (λ in μm):

$$n^2 - 1 = \frac{0.6961663\lambda^2}{\lambda^2 - (0.0684043)^2} + \frac{0.4079426\lambda^2}{\lambda^2 - (0.1162414)^2} + \frac{0.8974794\lambda^2}{\lambda^2 - (9.896161)^2}. \quad (4.7)$$

Refractive Index of UV-Grade Synthetic Fused Silica*

Wavelength (nm)	Index of Refraction	Wavelength (nm)	Index of Refraction
180.0	1.58529	532.0	1.46071
190.0	1.56572	546.1	1.46008
200.0	1.55051	587.6	1.45846
213.9	1.53431	589.3	1.45840
226.7	1.52275	632.8	1.45702
230.2	1.52008	643.8	1.45670
239.9	1.51337	656.3	1.45637
248.3	1.50840	694.3	1.45542
265.2	1.50003	706.5	1.45515
275.3	1.49591	786.0	1.45356
280.3	1.49404	820.0	1.45298
289.4	1.49099	830.0	1.45282
296.7	1.48873	852.1	1.45247
302.2	1.48719	904.0	1.45170
330.3	1.48054	1014.0	1.45024
340.4	1.47858	1064.0	1.44963
351.1	1.47671	1100.0	1.44920
361.1	1.47513	1200.0	1.44805
365.0	1.47454	1300.0	1.44692
404.7	1.46962	1400.0	1.44578
435.8	1.46669	1500.0	1.44462
441.6	1.46622	1550.0	1.44402
457.9	1.46498	1660.0	1.44267
476.5	1.46372	1700.0	1.44217
486.1	1.46313	1800.0	1.44087
488.0	1.46301	1900.0	1.43951
496.5	1.46252	2000.0	1.43809
514.5	1.46156	2100.0	1.43659

*Accuracy $\pm 3 \times 10^{-5}$.

[1]Malitson, I.H. "Interspecimen Comparison of the Refractive Index of Fused Silica," *Journal of the Optical Society of America* 55, no. 10 (October 1965): 1205–1209.