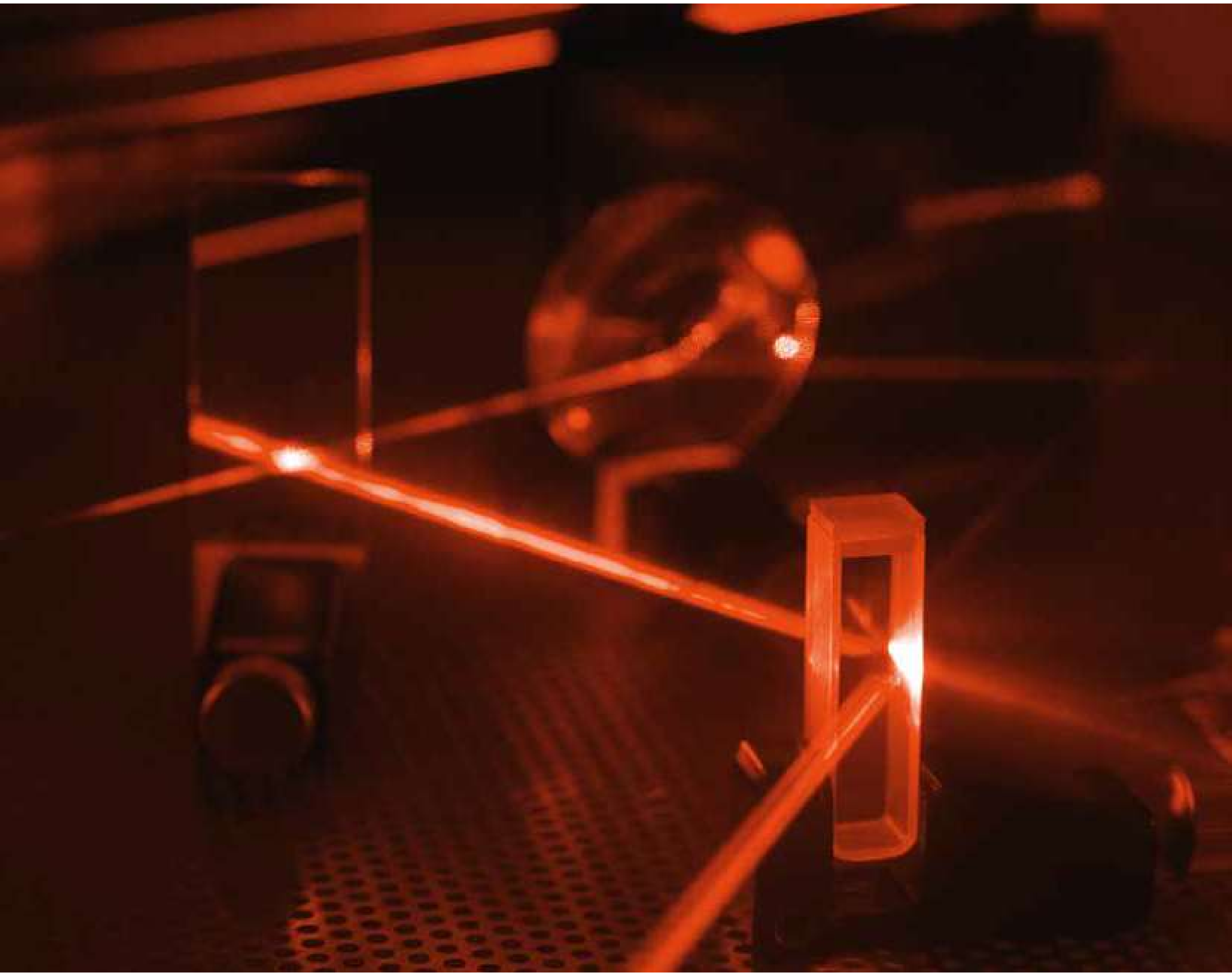


Fused Silica for Applications in the Near Infrared (NIR)

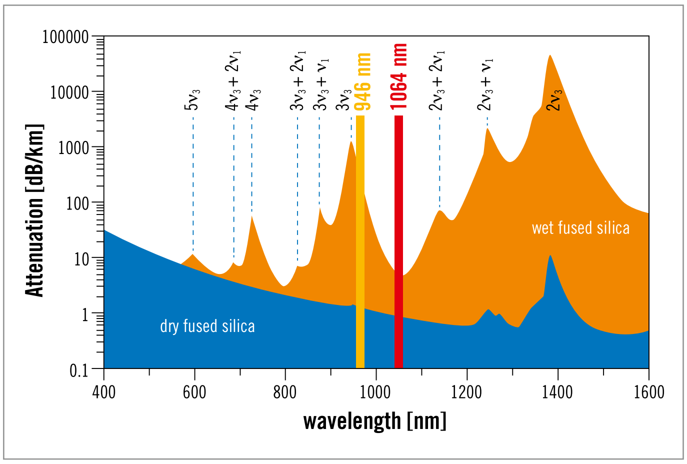
Ensuring performance of optical components in the NIR

The wavelength region from 800 nm to 3000 nm is defined as the near infrared (NIR) spectrum.

For all optical applications, it is important that the optical components transmit light with as little distortion as possible. For applications that use a laser an additional requirement is very low absorption. Absorption causes a local heating of the optical component. This heat can cause stress and a change in refractive index, resulting in focus shift. Absorption may not only cause poor performance, but could also result in damage and destruction of the optical component. It is therefore important to look deeper into absorption. There are two primary sources for absorption in the near IR: metallic impurities and OH groups. For synthetic fused silica the metallic impurities are typically in the ppb range and can be neglected.

Absorption due to OH

For the larger part of the NIR spectrum, the absorption is caused by OH molecules. These OH groups are present in the SiO_2 glass matrix due to the production process. Among other parameters, fused silica grades can be differentiated by their OH content. There are grades that have a very high, high, medium or low OH content.



Source: O.Humbach et al., J. Non Crystalline Solids, 203 (1996

The position of the vibrational or rotational excitation of the OH molecules in fused silica has been extensively analyzed in optical fibers, where it is the cause of signal attenuation. In the graph above we marked two lines: one where the influence of the OH content is large (yellow line) and one where it is small (red line). For those lines we will compare the performance of various fused silica grades.

To convert attenuation into absorption, the attenuation value in dB/km has to be multiplied with 2.3 to get absorption in ppm/cm.

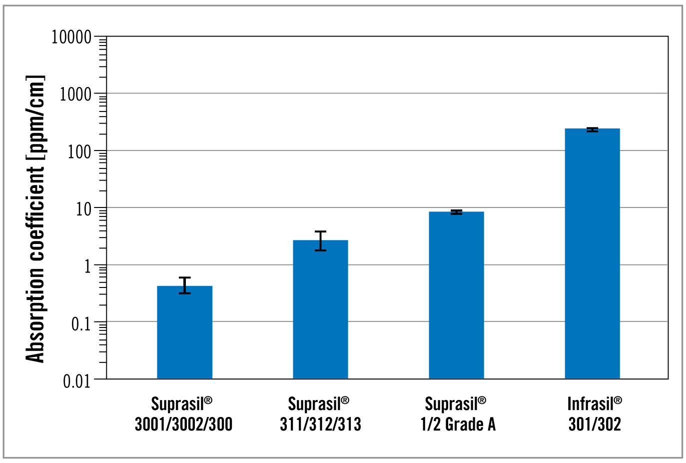
Example: In the graph above, the attenuation at 946 nm for a dry fused silica is 2 dB/km ➔ The absorption due to OH is 4.6 ppm/cm.

Measured absorption of different Heraeus fused silica grades

Absorption measurements on samples of Heraeus fused silica grades (Infrasil 30X, Suprasil 300X and Suprasil 31X) were done for the strong OH absorption case (946 nm) and the weaker OH absorption case (1064 nm).

MEASURED ABSORPTION AT 1064 NM:

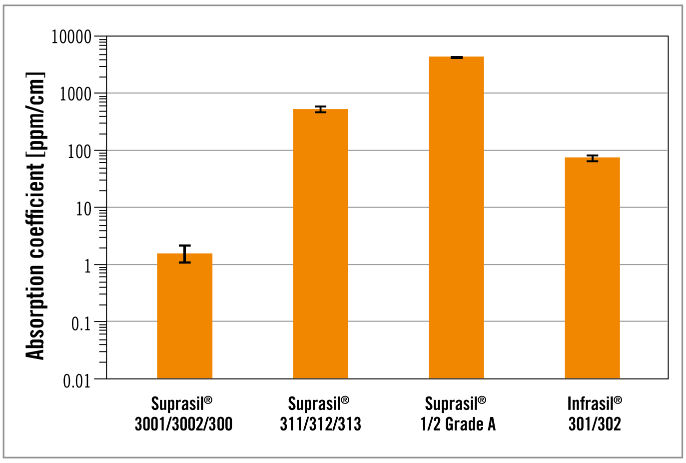
For applications at 1064 nm the OH content plays a minor role compared to the metallic impurities.



Measurements from Dr. Mühlig,
Institut für Photonische Technologien (IPHT), Jena

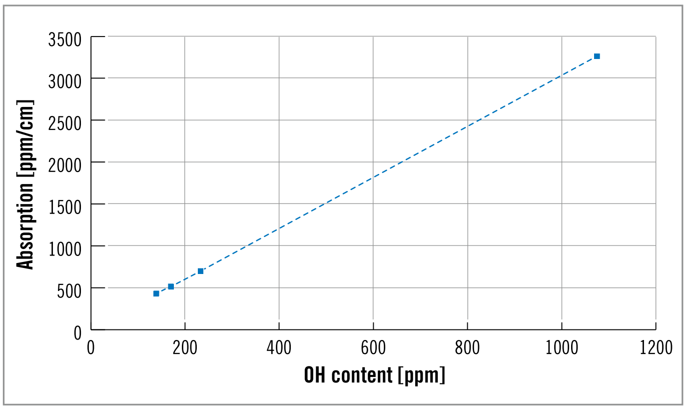
MEASURED ABSORPTION AT 946 NM:

The absorption at 946 nm is dominated by the OH content.



Measurements from Dr. Mühlig,
Institut für Photonische Technologien (IPHT), Jena

Plotting the measured absorption values at 946 nm in relation to the actual OH content of the sample, you obtain a straight line.



Correlation of absorption to actual OH content of the measured samples at 946 nm

For very low OH content the absorption due to metallic impurities comes into effect, therefore the chart is limited to about 100 ppm.

For applications at 1064 nm the OH content plays a minor role compared to the metallic impurities. All synthetic grades, even the high OH grades show a low absorption.

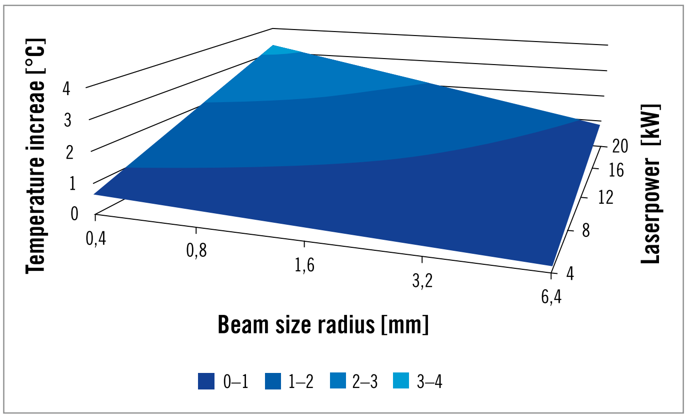
Simulation of temperature effect of different absorption values

In a simple simulation, the temperature increases due to a laser beam being absorbed by the glass. It can be calculated using measured attenuation values. The simulations are based on:

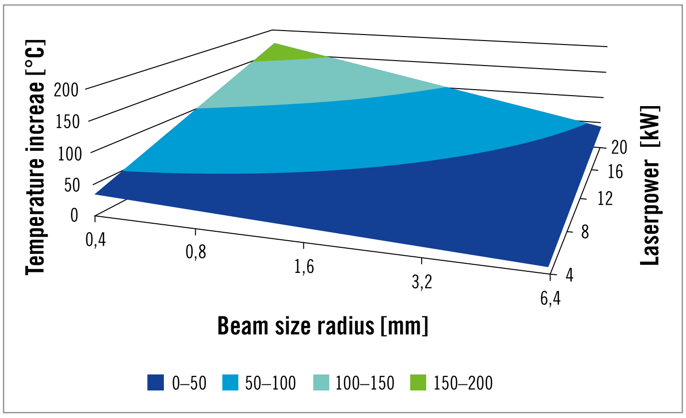
- A square fused silica sample with 50 mm edge length and 20 mm thickness.
- Continuous wave (CW) Laser of a given wavelength with power and beam size as variables.
- Steady-state diffusion equation with bulk and surface heat sources.
- Convective cooling with a heat transfer coefficient of 10 W / (m²*K) and ambient temperature of 25 °C.
- Clean surface and no surface influences on absorption.
- No temperature dependent absorption values

Fused silica can sustain quite high temperatures, but as mentioned before, locally heated glass will have a different refractive index and thermal inhomogeneities will cause stress in the glass. Both of these effects will cause wave front distortion and focus shift.

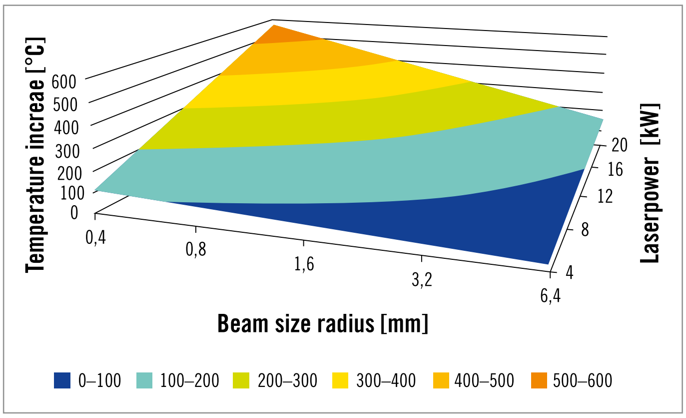
Additionally, optical components are typically coated and the coating materials or their adhesion to the glass are much more sensitive to elevated temperatures. For optimal performance and highest lifetime, it is necessary to keep the temperate increase to a minimum.



ABSORPTION AT 1.5 PPM/CM:
Only minimal change of temperature due to absorption, even for highest power densities (reference material: Suprasil 300X at 946 nm)



ABSORPTION AT 80 PPM/CM:
Works well, for low and medium power densities, but not suitable for high power applications (reference material: Infrasil at 946 nm)



ABSORPTION AT 265 PPM/CM:
Works only for low power densities, or thinner glass components than the 20 mm thickness used for simulation (reference material: Infrasil at 1064 nm, for Suprasil 31X lower end of OH distribution at 946 nm)

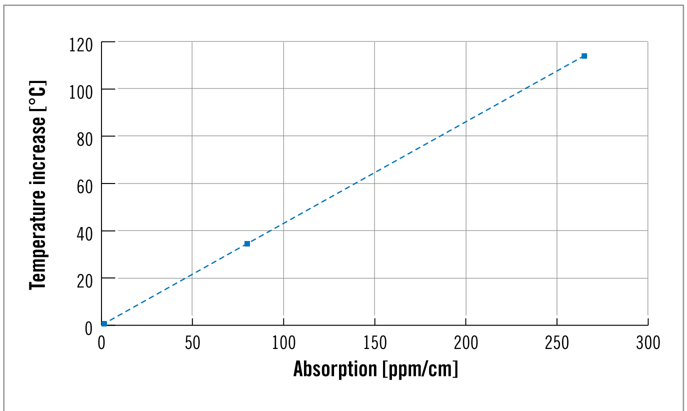
Choosing the right grade for your application

The effect of the temperature increase on the system performance depends on the individual system, what component is affected, and in what function. Therefore, a general rule of what kind of absorption is tolerable for what application cannot be given. However, an indication is possible.

To find possible solutions, you need to consider the absorption of the glass, the beam size and the power of the system. The simulation charts show the temperature increase depending on a fixed absorption value of the glass. The laser power and the beam radius are variables. Let us look at the graph with 80 ppm/cm absorption:

The temperature of the glass increases by 170 °C, if irradiated with 20 kW beam with a radius of 0.4 mm. A 4 kW beam with the same 0.4 mm radius results in a 35 °C temperature increase. If the 4 kW beam has a 6.4 mm radius, the temperature increases only by 9 °C.

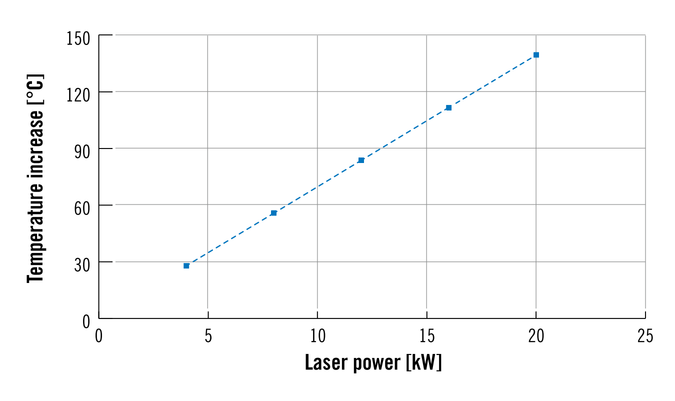
Now taking the various simulation results, this simple model allows to plot the temperature increase for a fixed beam size and beam power. The temperature difference depends linearly on the absorption of the glass.



Dependency of the temperature increase on the actual absorption of the simulated fused silica piece, for a 4 kW power beam with 0.4 mm radius.

Let's assume your 4 kW system (Beam radius 0.4 mm) can tolerate a temperature increase of 40 °C, with the linear extrapolation given above the 20 mm thick glass component needs to have an absorption below 100 ppm/cm.

Another linear extrapolation is possible for a fixed absorption and the fixed beam radius, allowing us to estimate the maximum power of a beam with 0.8 mm radius in a piece of glass of 50 x 50 x 20 mm to keep the temperature increase below 50 °C. From the chart you can read the power to be 7 kW.



Dependency of the temperature increase of a fused silica piece 50x 50 x 20 mm with an absorption of 80 ppm/cm on the laser power for a beam radius of 0.8 mm.

CONCLUSION:

The simulations show the general way how to select the right fused silica grade, elaborating on the effect of bulk absorption resulting in a temperature increase under laser irradiation.

The real performance of any fused silica component depends not only on the absorption of the fused silica glass, but also on the exact geometry of the component and the properties of the coating. A thinner part has a shorter absorption path length, a higher ratio of cooling surfaces to the heat generating volume (due to bulk absorption), which results in a smaller temperature increase.

TYPICAL NIR APPLICATIONS INCLUDE:

- Laser material processing
- High precision interferometry
- Spectroscopy
- Medical applications
- High energy lasers

TYPICAL FUSED SILICA COMPONENTS FOR THE NIR INCLUDE:

- Lenses
- Beam splitters
- Windows
- Debris shields
- Prisms
- Optical light guides

Heraeus grades for the NIR wavelength region

SUPRASIL® 3001, 3002 AND 300

These high purity synthetic fused silica materials are manufactured by flame hydrolysis. They combine excellent physical properties with outstanding optical characteristics in the near IR. During the manufacturing process an intermediate drying step reduces the OH content of the Suprasil 300 grades to below 1 ppm. A chlorine content of 1000 ppm – 3000 ppm is inherent to the material and results in a slight shift of the UV-absorption edge to the longer wavelength region.

The Suprasil 300 family combines ultra-low total metallic impurities (< 1 ppm) and low OH (< 1 ppm) that results in no absorption bands from the visible to the IR spectral region. This property makes this material family the best material for any low absorption application in the near-IR.

FEATURES

Material of choice for high performance applications in the near-IR

- Very low OH content (< 1 ppm)
- Ultra low total metallic impurities (< 1 ppm)

INFRASIL® 301 AND 302

Infrasil is manufactured by fusing refined natural quartz in an electrically heated furnace. This production route results in a very low OH content. NIR absorption for this grade is dominated by metallic impurities, there is only a small contribution by the low OH content. For low intensity applications Infrasil is a very good choice.

FEATURES

Material of choice for low intensity applications and a cost-efficient solution

- Low OH content (≤ 8 ppm)

SUPRASIL® 311, 312 AND 313

Suprasil 31X is produced in a similar way to the Suprasil 300 family. However, it does not contain Chlorine and is therefore not as dry. With an OH content of typically less than 250 ppm, it is not suitable for applications close to the OH absorption bands. However for applications away from these absorption bands the low metallic impurity content makes this material a good choice.

FEATURES

Cost efficient choice for applications aside the OH-absorption bands. Especially for thin glass parts, e.g. debris shields

- Medium OH content
- Ultra low total metallic impurities (< 1 ppm)

Summary

- Absorption causes a heating of fused silica. This results in changes in the refractive index, which can result in aberrations to the transmitted wave front or ultimately in the destruction of the part.
- A simple model helps to identify tolerable absorption values.
- The cause of the strongest absorption in the NIR is OH in the fused silica matrix. The impurity level also plays a role, if the OH content gets low.
- Low OH grades are preferred for NIR applications.
- Suprasil® 3001, 3002, 300 are the best choice for near infrared applications where performance matters. Infrasil® 301, 302 is a suitable alternative for applications requiring combined very good NIR performance and economy.

Material	Wavelength	Remark	Application	Power density level
Suprasil® 3001	200 nm – 3500 nm	Lowest absorption	Highest quality optics	Highest
Suprasil® 3002			Highest quality 2D optics	
Suprasil® 300			Windows, lenses with medium need for homogeneity	
Infrasil® 301	270 nm – 3500 nm	High cost efficiency	3D applications, e. g. high grade prisms	Medium
Infrasil® 302			2D applications, e. g. lenses, windows	
Suprasil® 311	190 nm – 1100 nm	Very low absorption at 1064 nm	3D applications, e. g. high grade prisms	Most cost effective for 1064 nm applications
Suprasil® 312			2D applications, e. g. lenses, windows	
Suprasil® 313			Windows, lenses with medium need for homogeneity	

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