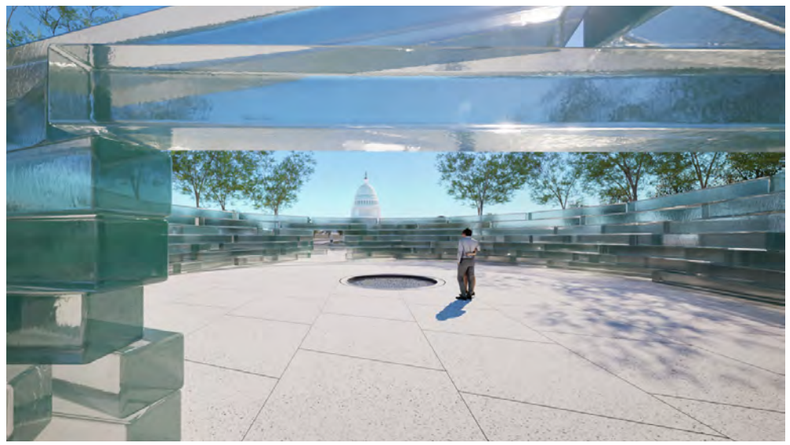


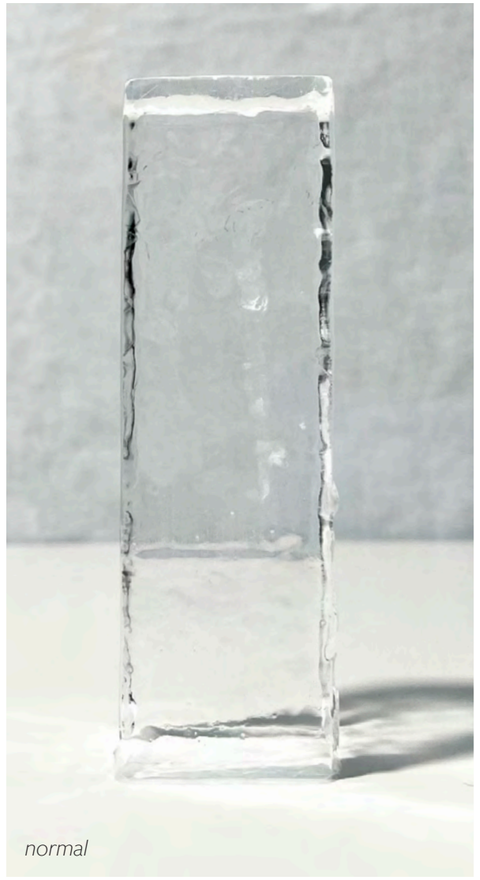
# Fallen Journalists Memorial

## Glass Research

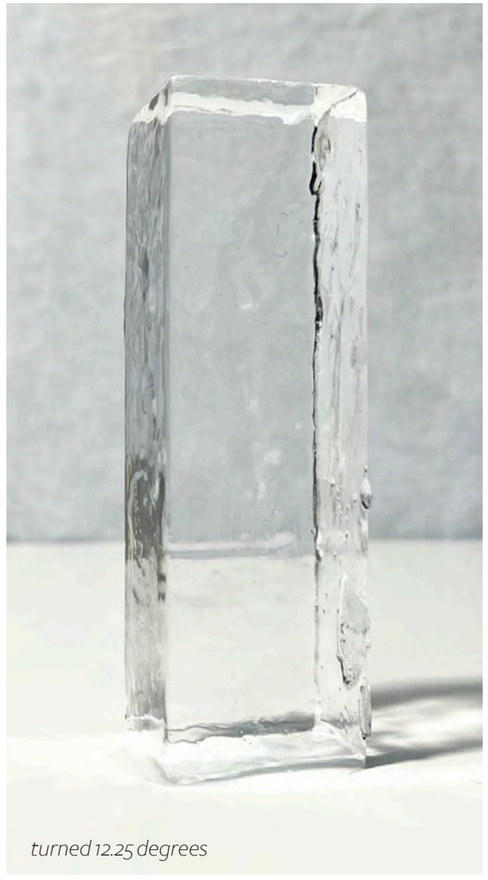
22 July 2024

**John Ronan Architects** Chicago

An investigative journalist sheds light on issues obscured in darkness. They clarify factual distortions and explain what is difficult to comprehend, making what is opaque become clear. Similarly, the memorial should engage with themes of transparency, opacity, distortion, clarity and light.

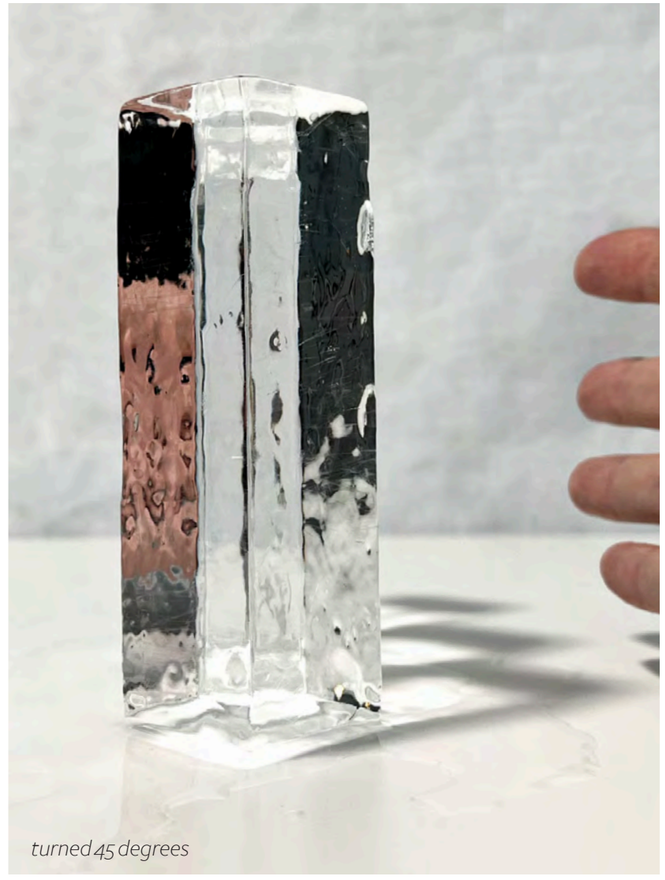


*normal*



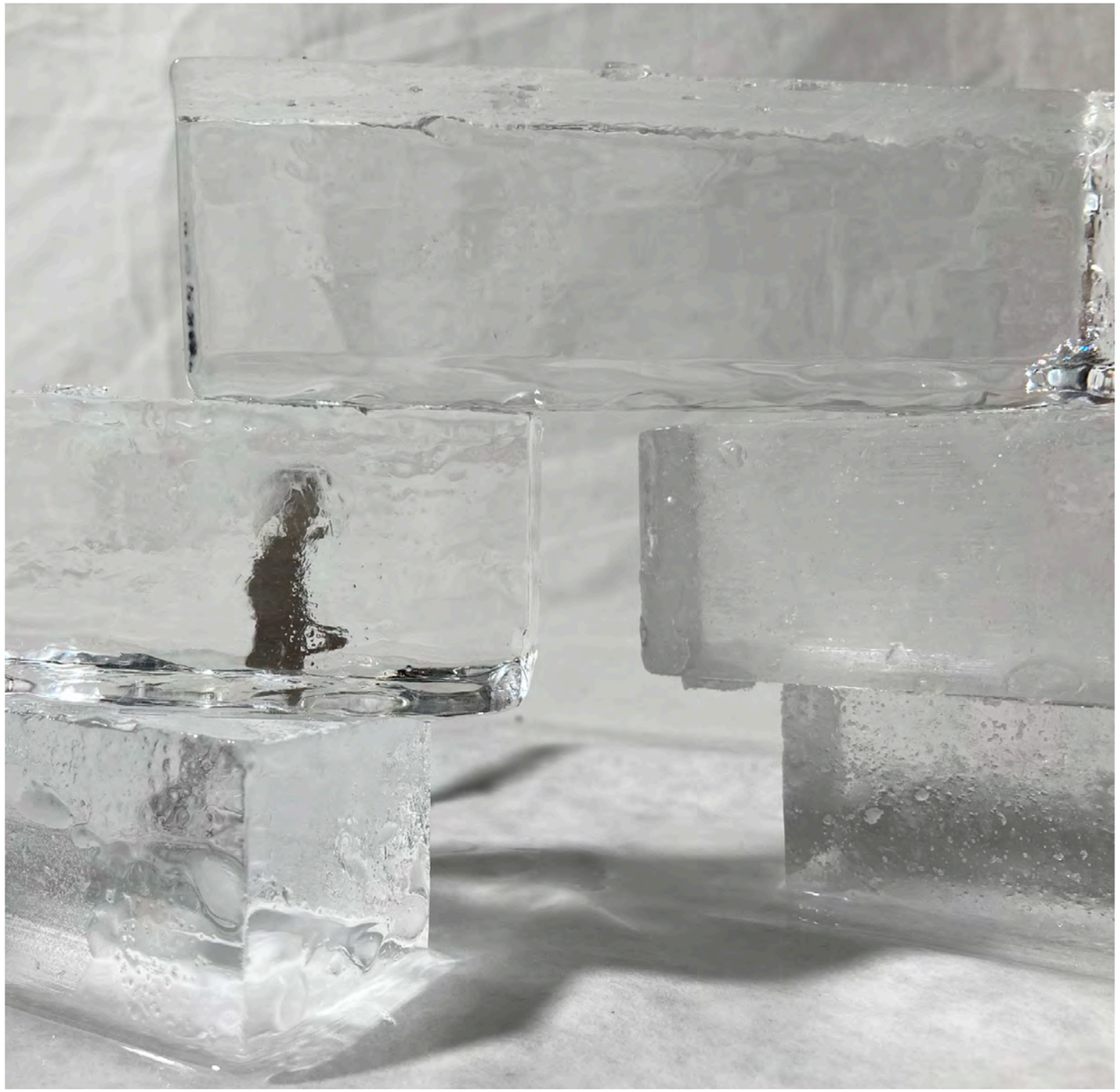
*turned 12.25 degrees*

*turned 22.5 degrees*

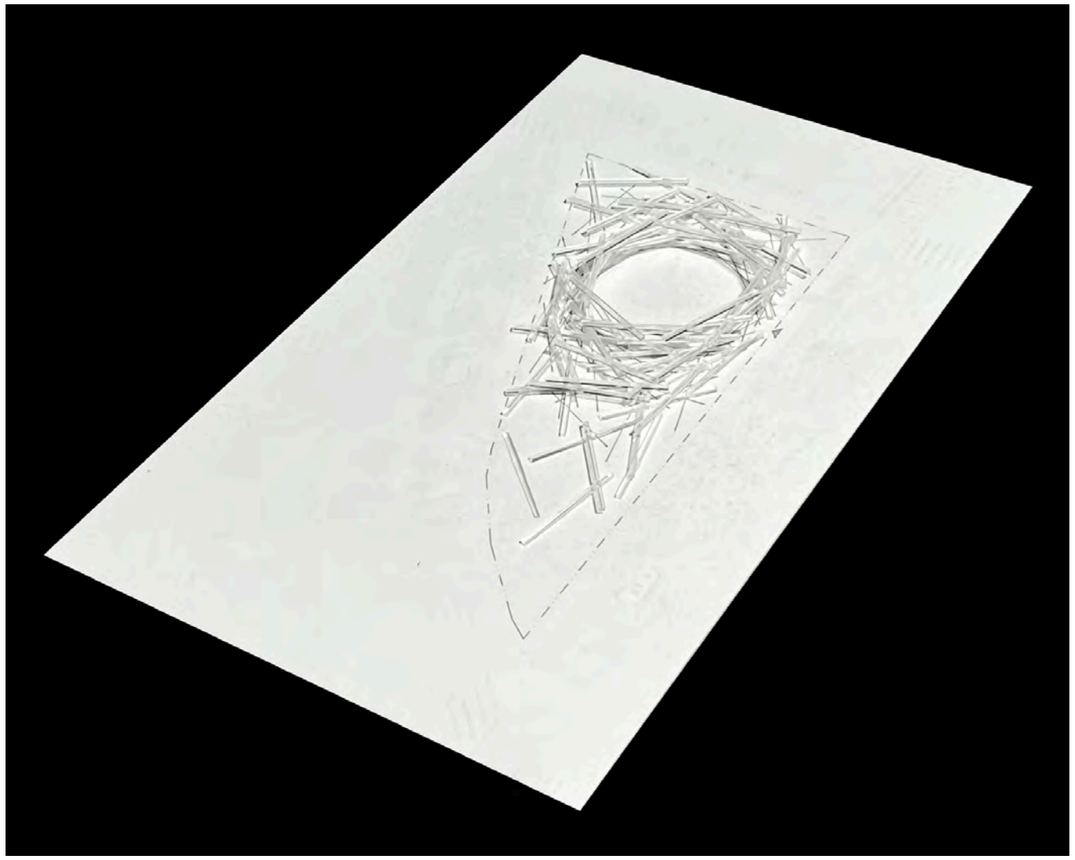


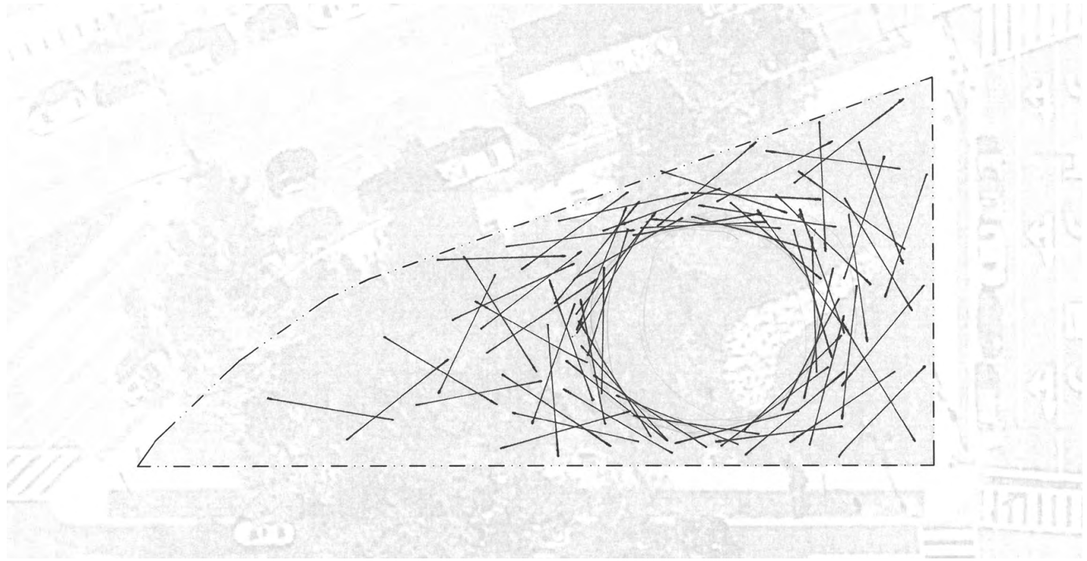
*turned 45 degrees*

To explore these themes, we began by studying ice, which can be transparent, distorted, or opaque, depending on the viewer's perspective.



Stacking the ice elements, we noticed how reality can be distorted by the positioning of the stacked ice elements.





## Memorial as Story

The memorial design consists of a collection of transparent, solid glass elements arranged on the site in a seemingly accidental manner which aggregate to form a pure cylindrical space at the heart of the site, suggesting the way ostensibly disconnected facts coalesce to form a journalist's story.

Experiencing the memorial is a **journey of discovery** that unfolds slowly, space by space like a story, and casts the visitor in the role of investigative journalist pursuing truth wherever it leads.

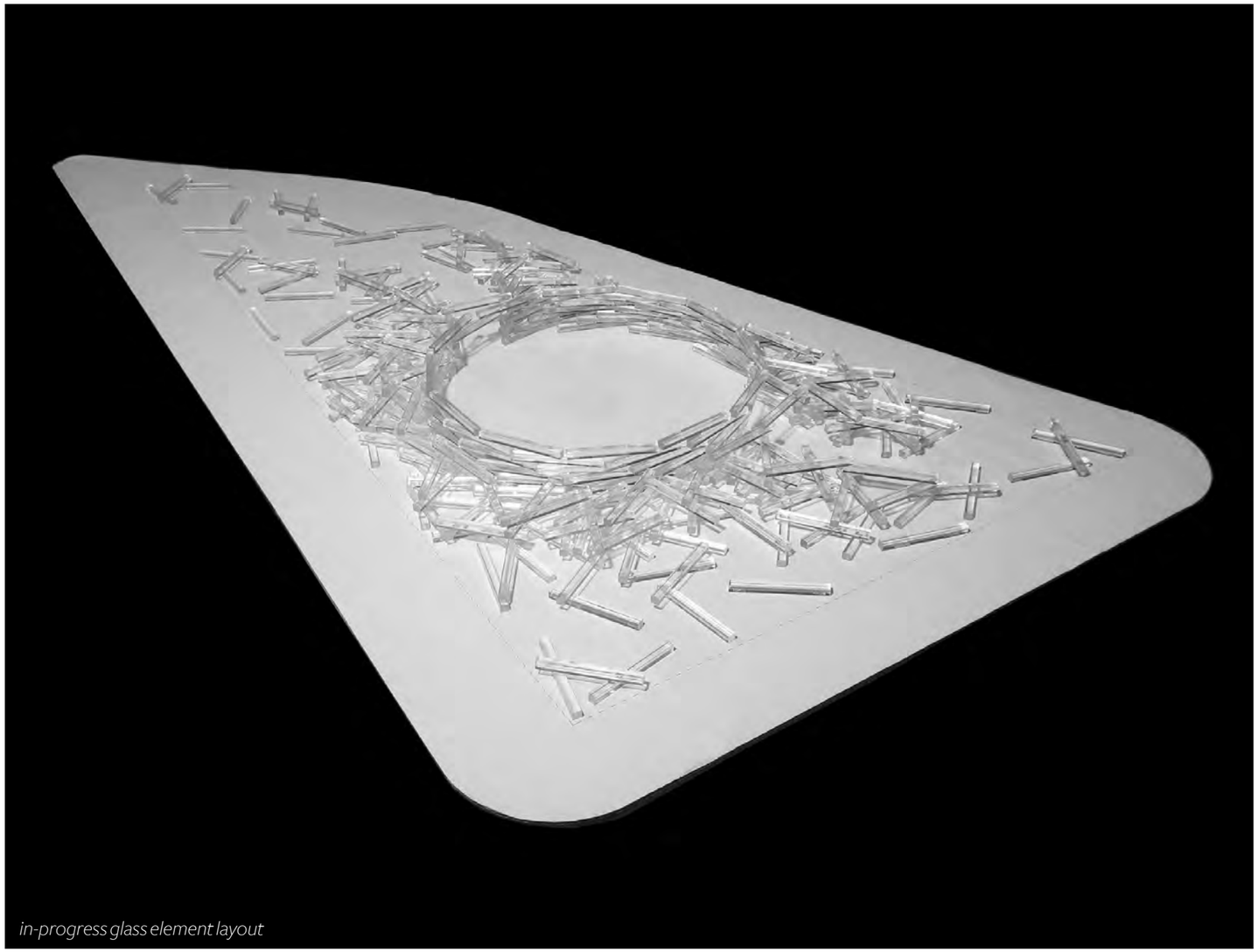
22 july 2024 **concept model**

The memorial can be entered from multiple sides with all paths leading to the circular Remembrance Hall, suggesting that there are many paths to the truth, none of which are linear.

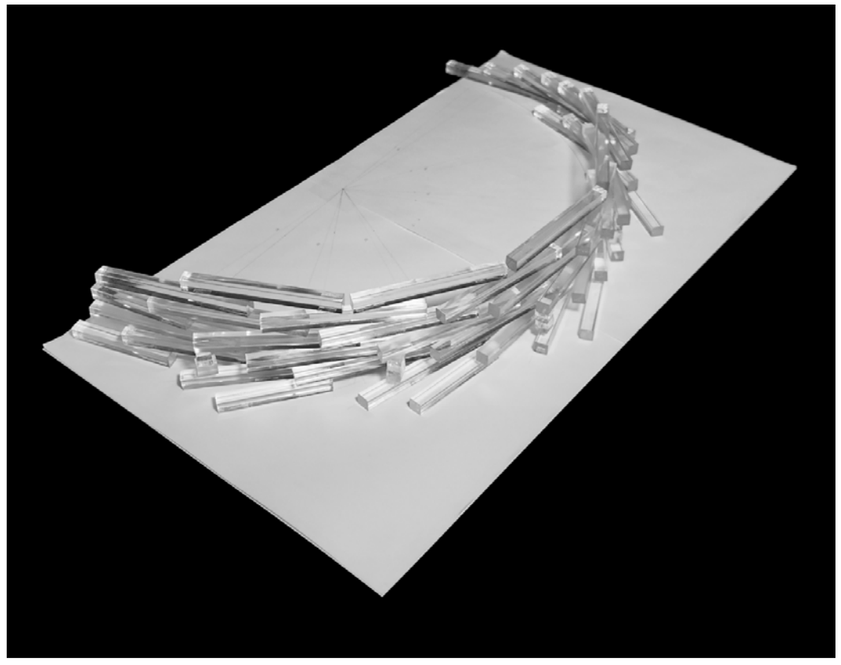
22 july 2024 **view looking west**

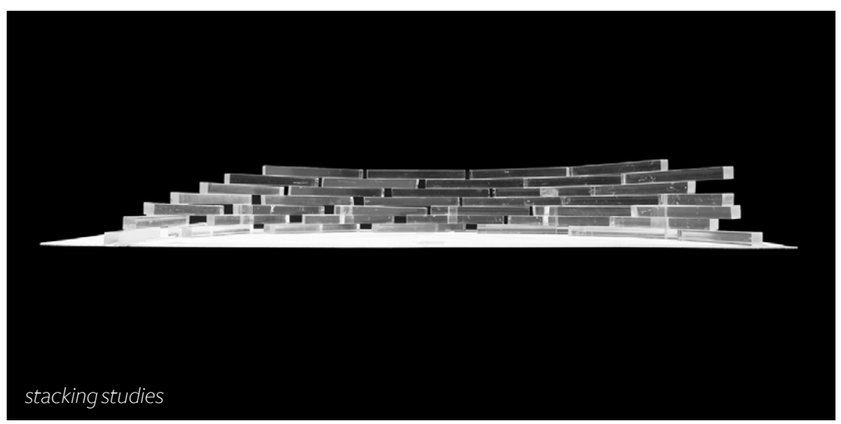
Like a newspaper headline, the memorial appears intriguing at first glance, inviting the visitor in to explore further. As visitors are drawn into the memorial, the glass elements increase in number and density, like facts in a journalist's story.

At night, a soft glow emanates from the site, and the memorial becomes a beacon of truth. Symbolizing the role journalists play in shedding light on conditions obscured in darkness.



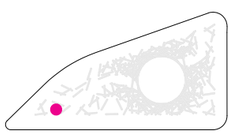
*in-progress glass element layout*





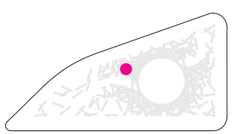
*stacking studies*

Solid clear acrylic bars are used to study empirically the disposition on the site of the glass elements that form the memorial's path of discovery.

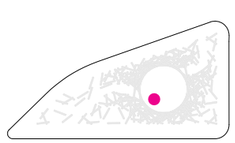


The shaded areas of the memorial provide a comfortable and inspiring public place for people to eat lunch, relax or meet with friends.

22 july 2024 **view looking east**

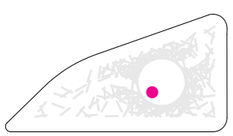


The memorial experience unfolds slowly, space by space like a story, and casts the visitor into the role of investigative journalist, following the facts, wherever they lead, in the pursuit of truth.



The circular Remembrance Hall is the memorials "home for truth." Upon entering it, disorder yields to order, and things fall into place. The Capitol dome comes into view, signifying the watchdog role that journalists play in a democracy, and visitors are drawn to a circular glass "lens" in the center of the space bearing an important message: the text of the First Amendment to the U.S. Constitution.

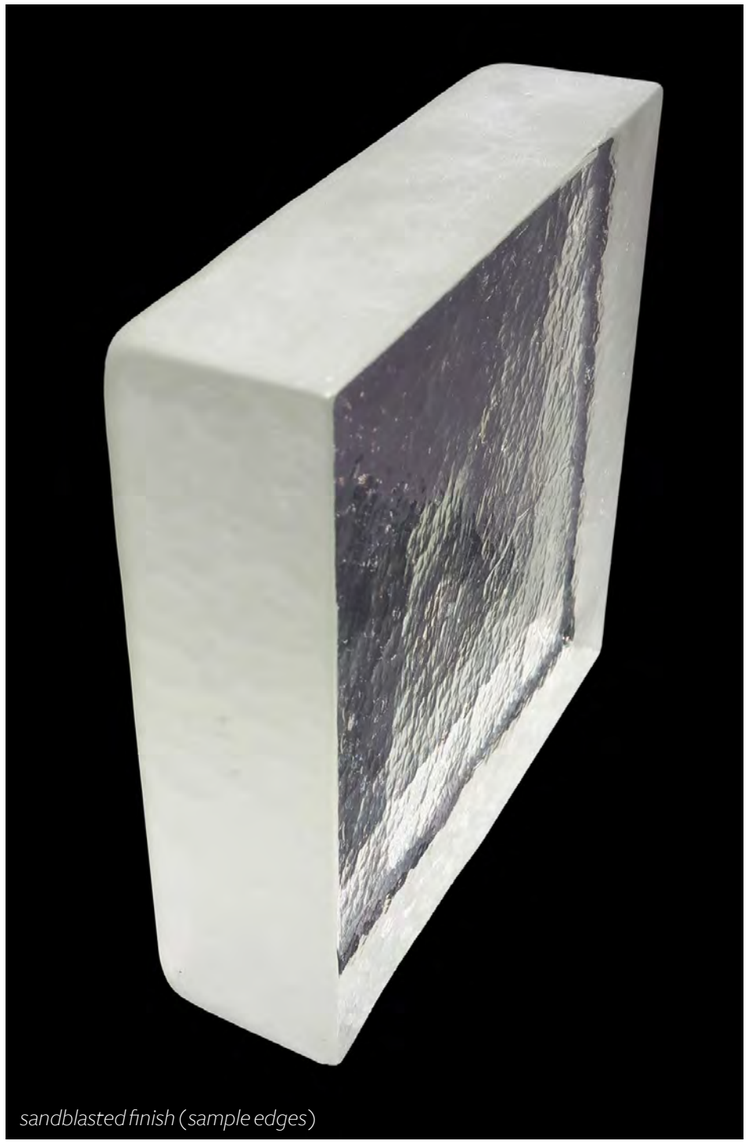
Looking downward into the lens to read its message, the visitor's own reflection gazes back, implying that each one of us has a role to play in protecting First Amendment freedoms, to properly honor the sacrifice of those remembered here.



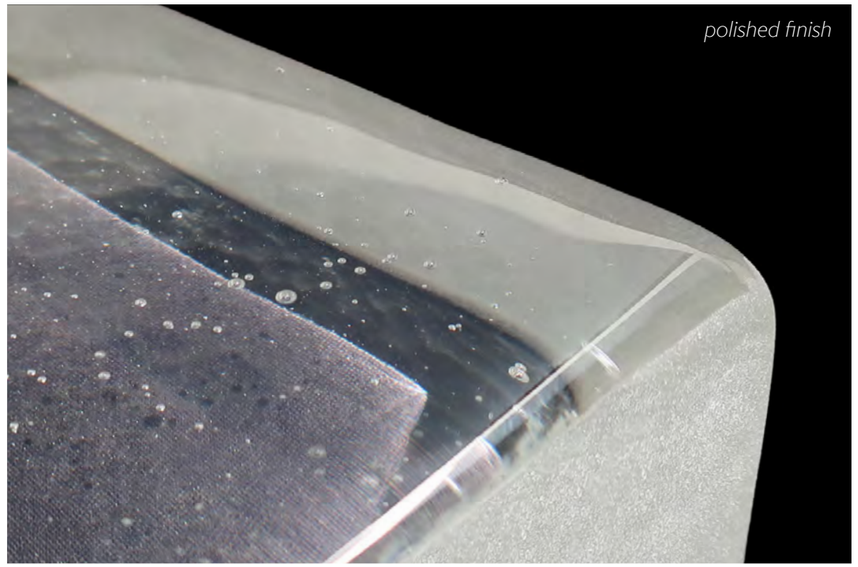
At night, a soft glow emanates from the up-lit glass elements, creating an atmosphere of quiet reflection where those who have sacrificed their life in pursuit of the truth are honored, and First Amendment rights are celebrated.

**Borosilicate glass** is a type of glass containing boron trioxide which allows for a very low coefficient of thermal expansion. It is thermal shock resistant and will not crack under extreme temperature changes like regular soda-lime glass. (Pyrex is a form of borosilicate glass)

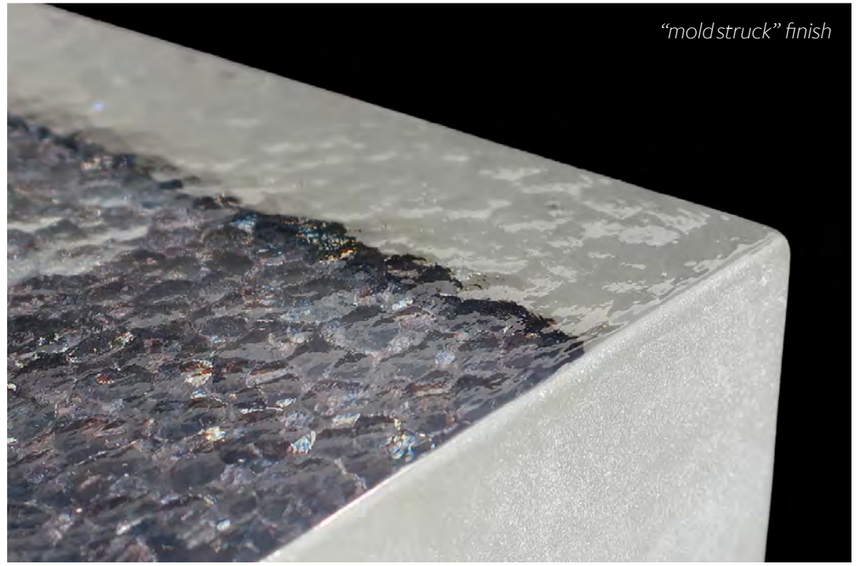
The memorial will need to **be unique** and **unconventional** to stand out amidst a crowded field. Solid elements of cast glass is the proposed material and main protagonist of our story. Each glass element will be unique and slightly different, to represent the unique personal story of each journalist remembered here.



*sandblasted finish (sample edges)*



*polished finish*



*"mold struck" finish*

***will the glass become hot to the touch?***
glass does not reflect heat, but instead heat passes through glass, with only small amounts absorbed. this is why thermometers still use glass, and why the heat from the sun passes through a window and can be felt on the inside of a house (it should be noted that the bench-height glass elements in our scheme are located under shade trees for added human comfort).

***will the glass break?***
high grade borosilicate glass is the strongest glass made and is resistant to thermal shock.

***how long does glass last?***
essentially, the decomposition rate of glass is none. there are no microorganisms on planet earth able to break down glass materials, and since it takes thousands of years, there is not a single glass bottle on the planet that has even come close to decomposing. it is speculated that it takes over 4000 years for glass to break up and decompose.

***how will the glass elements be connected?***
stacked glass elements will be installed with a silicone pad between them to cushion and adhere them together.

***is glass easy to maintain?***
yes. periodic cleanings (every 4-6 weeks) using ordinary water from the municipal supply will supplement the natural cleaning provided by rain water. glass elements are scratch resistant, they change little over time and will not rust or fade. in addition, graffiti can be removed easily from glass without special tools or chemicals that might stain or change the appearance of other materials.

*What is the difference between soda-lime and borosilicate glass?*

**Soda-Lime glass** is the most common type of glass due to its workability and affordability (over 90% of glass used in commercial applications is soda-lime glass). It consists of roughly 60-70% silica, 13% sodium dioxide (soda), and 9% calcium oxide (lime), along with other trace elements.[1][2][5]

**Borosilicate glass** is a specialty glass invented in the 1880's by Otto Schott, designed to withstand extreme thermal, chemical, and mechanical conditions.[3] It contains roughly 80% silica and 13% boron oxide.[2][4][5] The high concentration of both silica and boron oxide gives the borosilicate glass a number of benefits over traditional soda-lime glass, including:

- Toughness and Scratch Resistance

  borosilicate glass has significantly increased durability and surface hardness compared to soda-lime.[3]

- Thermal Expansion and Shock Resistance

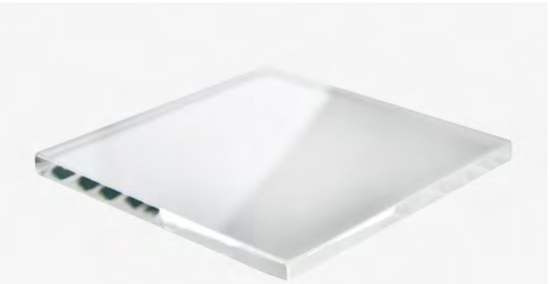
  borosilicate glass has less than half the thermal expansion and contraction rate of soda-lime glass, making it highly resistant to cracks and breakage as a result of thermal shock.[2][3]

- Chemical Stability

  borosilicate glass is very chemically stable, meaning it will resist attack by corrosive agents. [2][3]

- Optical Clarity

  borosilicate is used in optical applications due to its clarity and high light transmittance. (in comparison, soda-lime glass is less clear and often has a blue-green tint due to its high iron content.)[3]



*borosilicate glass*

Borosilicate glass is used in many different applications where high performance is required, including laboratory glassware, cookware and kitchen equipment, optics, medical devices, and electronic components.

*telescope mirror blank*

*vacuum tube housing*

*kitchen cookware*

*laboratory glassware*

*optical lens*

footnotes: **1.** Britannica, "soda-lime glass." *https://www.britannica.com/technology/soda-lime-glass* **2.** Wondrwood, "What is Borosilicate Glass." *https://wondrwood.com/blogs/what-were-working-with/what-is-borosilicate-glass-why-is-it-better-than-regular-soda-lime-glass* **3.** Schott, "Borosilicate Glass." *https://www.schott.com/en-dk/expertise/materials/borosilicate-glass* **4.** Schott, "Schott - Technical Glasses - Physical and Technical Properties." Mar. 2020 (*see appendix*) **5.** camlab, "Borosilicate glass vs Soda Lime glass vs Pyrex - what is the difference?" *https://www.camlab.co.uk/what-types-laboratory-glassware-should-you-use*

1. Strength and Durability

***Mechanical Properties:*** *Provide data on the compressive, tensile, and flexural strength of borosilicate glass.*

Mechanical properties of borosilicate glass will differ slightly from manufacturer to manufacturer due to variations in chemical composition but are conservatively considered for design as follows:

| | |
|---|---|
| Compressive Strength: | **290** ksi |
| Tensile Strength: | **41** ksi |
| Flexural Strength: | **5** ksi |
| Modulus of Elasticity: | **9,000** ksi |

See **table A** (following page) for mechanical properties comparison of borosilicate glass to other materials commonly used in memorials.

footnotes: **1.** Make It From, "Borosilicate Glass." https://www.makeitfrom.com/material-properties/Borosilicate-Glass

| | | definition | borosilicate glass | granite | marble | unreinforced concrete | stainless steel | remarks |
|---|---|---|---|---|---|---|---|---|
| mechanical properties | **density** | amount of mass per unit volume | **140** lb/cu ft [12] | **162** lb/cu ft [10] | **168** lb/cu ft [10] | **140** lb/cu ft [3] | **490** lb/cu ft [2] | borosilicate glass is a similar density to granite, marble, and concrete. |
| | **compressive strength** | resistance of a material to breaking under compression | **290** ksi [7] | **320** ksi [8] | **78** ksi [9] | **3** ksi [3] | **30** ksi [2] | borosilicate glass has **greater** compressive strength than marble, unreinforced concrete, and stainless steel. it is similar to granite. |
| | **tensile strength** | resistance of a material to breaking under tension | **41** ksi [7] | **5.1** ksi [8] | **1.3** ksi [9] | **0.3** ksi [3] | **74** ksi [2] | borosilicate glass has **greater** tensile strength than granite, marble, and unreinforced concrete |
| | **flexural strength** | resistance of a material to breaking under bending | **5** ksi [7] | **3.5** ksi [8] | **2.2** ksi [10] | **0.3** ksi [3] | **30** ksi [2] | borosilicate glass has **greater** flexural strength than granite, marble, and unreinforced concrete |
| | **knoop hardness** | measure of a material's surface hardness, or its resistance to scratching and abrasion. | **480** [12] | **550 - 650** [1] | **140 - 180** [1] | **550-850** [14] | **166** [6] | borosilicate glass is **harder** than marble and stainless steel, and is similar to granite. |
| thermal properties | **thermal expansion coefficient** | rate at which a material expands with increase in temperature | **3.3 x 10$^{-6}$** K [11] | **7.9 - 8.4 x 10$^{-6}$** K [5] | **5.5 - 14.1 x 10$^{-6}$** K [5] | **13 - 14 x 10$^{-6}$** K [5] | **16 x 10$^{-6}$** K [2] | borosilicate glass will be the **most stable** material when undergoing temperature changes. |
| | **thermal conductivity** | the ability of a material to transfer heat energy to and from its surroundings. | **1.2** W/m-K [12] | **1.7 - 4.0** W/m-K [4] | **2.0 -2.9** W/m-K [4] | **1.0 -1.8** w/m-K [4] | **16.2** W/m-k [6] | borosilicate glass will conduct over **10x less heat** than stainless steel, and is similar to concrete. |
| | **specific heat capacity** | the amount of energy required to raise the temperature of a material by 1 unit. | **0.83** [7] | **0.79** [13] | **0.88** [13] | **0.88** [13] | **0.50** [6] | borosilicate glass will gain **less hea**t than stainless steel, and a similar amount to granite, marble, and concrete. |

footnotes: **1.** AutoDrill, "Knoop Material Hardness Scale." www.autodrill.com/wp-content/uploads/2012/06/HardnessScaleChart.pdf **2.** AZoM, "Properties: Stainless Steel - Grade 304." 11 June 2024, www.azom.com/properties.aspx?ArticleID=965 **3.** Engineeringtoolbox, "Concrete Properties." 8 Sept. 2023, www.engineeringtoolbox.com/concrete-properties-d_1223.html **4.** Engineeringtoolbox, "Solids, Liquids and Gases - Thermal Conductivities." 22 Apr. 2024, www.engineeringtoolbox.com/thermal-conductivity-d_429.html **5.** Engineeringtoolbox. "Thermal Expansion - Linear Expansion Coefficients." 2 Nov. 2023, www.engineeringtoolbox.com/linear-expansion-coefficients-d_95.html **6.** EZLOK, "316 Stainless Steel Mechanical Properties." www.ezlok.com/316-stainless-steel-properties **7.** Make It From. "Borosilicate Glass." https://www.makeitfrom.com/material-properties/Borosilicate-Glass **8.** Make It From. "Granite." https://www.makeitfrom.com/material-properties/Granite **9.** Make It From. "Marble." https://www.makeitfrom.com/material-properties/Marble **10.** Modul Marble, "Physical Mechanical Characteristics Natural Stone." modulmarble.com/wp-content/uploads/2019/05/Natural-Stone-Physical-Mechanical-Characteristics.pdf **11.** Schott, "Schott - Technical Glasses - Physical and Technical Properties." Mar. 2020 **12.** Schott, "Schott Borofloat 33 - Technical Data" **13.** Wikipedia, "Table of Specific Heat Capacities." 30 May 2024, en.wikipedia.org/wiki/Table_of_specific_heat_capacities. **14.** Becosan, "How to measure the hardness of concrete and why it is important." https://www.becosan.com/how-to-measure-the-hardness-of-concrete-and-why-it-is-important/

***Impact Resistance:*** *Information on how the glass performs under impacts, including any treatments or laminations that increase its toughness.*

Impact resistance is the measure of a material's ability to withstand intense force or shock.

While limited cast glass impact load test data is available, homogeneous borosilicate samples have demonstrated greater performance than other glass materials or fused specimens. Borosilicate glass has greater mechanical strength than stone and a higher Mohs Hardness, allowing it to absorb more energy before failing. If necessary, potential means to improve impact resistance include strengthening the glass surface with modified heating, cooling, or annealing processes.

Vehicle impact loads are derived from the building code requirements for passenger vehicle barriers, approximately equivalent to a moving 6,000 lb vehicle. Each glass element will weigh over **3,000 lbs.**

***Load-Bearing Capacity:*** *Maximum weight the glass blocks can safely support, especially for benches.*

Structural design load considerations consist of criteria determined by the International Building Code to include occupant gravity loads, environmental wind, seismic and thermal loads

Gravity loads are based on the code's public assembly spaces requiring 100 psf applied to the top surface of the glass blocks, equivalent to 200 lb individuals spaced every 19" along its entire length. This fully loaded bench is only at **10% of its allowable load capacity.**

Wind and seismic loads are established based on exposure and site geotechnical conditions.

***Structural Connections:*** *Information on how the glass blocks are connected to each other and to the ground surface.*

There are multiple **connection strategies** that will be explored, including:

A **mechanical interlock** between glass elements with no silicone adherant or sealant.

Clear silicone spacers at the interface between glass elements, fully adhered with a silicone based adhesive. The spacers accommodate the uneven texture of the glass surfaces, field tolerances, and localized movements while restraining distortions of the overall geometry. Glass elements are carefully arranged on the site to ensure uniform load distribution and to eliminate the need for hold down brackets.

There are numerous **adhesive** options that will be explored, including:

A photo-curing family of clear adhesives used in the cast glass masonry wall of Crystal House (see **precedent E**), chosen for its high shear stiffness and good long and short term compressive behavior. Visually, the adhesive is similar to glass and does not discolor in sunlight.

There are adhesives available that incorporate resistance to ultra-violet light. The design team will conduct extensive testing on adhesives, including accelerated aging tests in a UV cabinet (*see photo*).

The design team will work closely with DOW to formulate an adhesive specifically formulated for the requirements of the Fallen Journalists Memorial project.

See **table B** (following page) for comparison of different glass adhesives. Mock-ups will be developed to test the various adhesives to determine which product is most suitable for the project.

(*above*)
*crystal house facade*
(***precedent E***)

(*middle*)
*dowsil crystal clear spacer*

(*bottom*)
*accelerated aging testing of adhesives for ultra-violet resistance*

The table below lists just some of the many products that have been used in cast glass structures:

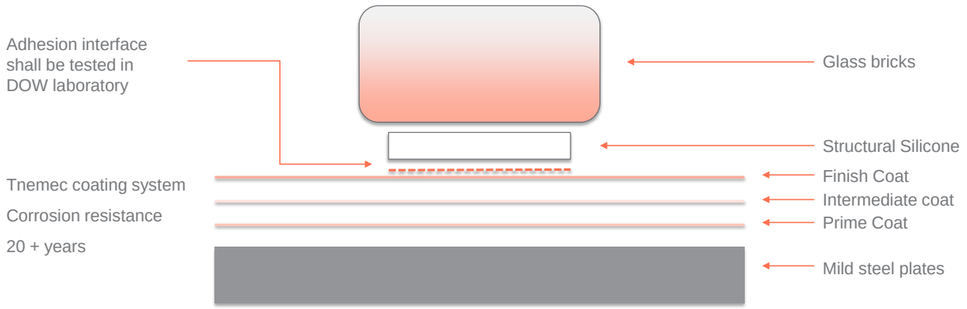
| | | | adhesives | | | | | | | | | | pads | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **manufacturer** | | | dow | dow | dow | delo | delo | delo | 3M | 3M | silco | silco | dow | rubbercal | rubbercal | the rubber company |
| product | | | **dowsil glass sealant** | **dowsil 2400 silicone assembly sealant** | **dowsil 993** | **photobond 4468** | **photobond 4497** | **photobond 4494** | **clear super silicone seal** | **scotch-weld polyurethane adhesive DP610** | **sil-flex ultraflex** | **sil-flex RTV-7500** | **crystal clear spacer** | **silicone rubber** | **silicone CG translucent** | **clear silicone sheet RC0323-TRAN** |
| **use** | | | glass adhesive & sealant | structural glass bonding | structural glazing | glass adhesive | multipurpose sealant | glass adhesive | automotive bonding | plastic glass metal adhesive | exterior construction | exterior construction | spacer material in IGU | high temp. gasket | high temp. gasket | gaskets and seals |
| **material** | | | silicone | silicone | silicone | modified acrylate | modified acrylate | modified acrylate | silicone | polyol-isocyanate | silicone | silicone | silicone cured elastomer | silicone | silicone | silicone |
| **color** | | | clear | clear | white | clear | milky | clear | clear | clear | clear | | clear | white | translucent white | clear |
| **precedent** | | | | | g | a,f | f | f | | h | | | | | | |
| mechanical properties | | definition | | | | | | | | | | | | | | |
| | **service temperature [F]** | the range of temperatures a sealant can endure while maintaining its durability and performance.[1] | -30F to 302F | -58F to 302F | -58F to 302F | -40F to 248F | -22F to 248F | -40F to 248F | -76F to 400F | -40F to 176F | -62F to 350F | -62F to 400F | | -103F to 450F | -103F to 450F | -67F to 392F |
| | **specific gravity [g/ml]** | the ratio of mass of a given volume of material at 23°C to the same volume of deionized water.[2] | 1.33 | 1.08 | 1.3 | 1.02 | 1 | 1 | 1.01 | 1.15 | 1.35 | 1.04 | | | | |
| | **tensile strength [MPa]** | tensile stress corresponding to the point of rupture [3] | 2.37 | 4.34 | 0.95 | 14 | 11 | 20 | 2.2 | 23 | 2.13 | 1.31 | 0.05 | 6 | 6 | 6.89 |
| | **elongation at break [%]** | tensile elongation corresponding to the point of rupture [3] | 384 | 1300 | 130 | 200 | 200 | 160 | 550 | | 410 | 650 | 80 | 300 | 300 | 450 |
| | **durometer hardness shore** | relative hardness of soft materials, usually plastic or rubber... measures the penetration of a specified indentor into the material under specified conditions of force and time. Shore A and Shore D hardness scales are common, with the A scale being used for softer and the D scale being used for harder materials. [4] | 32 Shore A | 60 Shore A | 40 Shore A | 50 Shore D | 90 Shore A | 62 Shore D | 25 Shore A | | 35 Shore A | 15 Shore A | 40 Shore 00 | 50 Shore A | 50 Shore A | 40 Shore A |
| **remarks** | | | cures at room temp. to a tough flexible rubber | excellent clarity dispense between 239F & 266F. Used onimpact glazing | two-part silicone rubber resistance to salt spray resistanct to $SO_2$ | single component light curing - 20 - 40 seconds exposure thickness of 0.2 - 0.3mm requires high flatness of substrate | exterior sealant used in photovoltaic construction | more viscous than 4468 - used at vertical joints in precedent e | fast cure flexible tested at 1/4in thick | flexible when cured | rubber-like when cured no change over 10,000 hrs accelerated weathering | rubber-like when cured no change over 10,000 hrs accelerated weathering | | smooth finish up to 1/4" thick | smooth finish up to 1/4" thick | centrifugally cast liquid silicone rubber washers, strips, gaskets, moisture protection |

footnotes: **1.** https://premierbuildingsolutions.net/2024/06/understanding-service-temperature-vs-application-temperature-of-sealants/#:~:text=Let's%20define%20these%20terms%3A,maintaining%20its%20durability%20and%20performance. **2.** https://www.intertek.com/polymers-plastics/testlopedia/density-and-specific-gravity-astm-d792/ **3.** https://plastics.ulprospector.com/properties/ASTMD412 **4.** https://www.intertek.com/polymers-plastics/testlopedia/shore-hardness-astm-d2240/

***Structural Connections:*** *Information on how the glass blocks are connected to each other and to the ground surface.*

The base level of glass elements will be elevated above the plaza surface and supported by 6” - 8” diameter stainless steel pipes at each end which project from concrete foundations below grade.

Mock-ups will be developed to test the multiple connection options to determine which is most suitable for the project.




*qwalala connection detail* (***precedent D***)

*steel support structure of qaammat pavilion* (***precedent F***)

***Lifespan:*** *Expected lifespan of the glass blocks under typical usage conditions?*

Essentially, the decomposition rate of glass is *none.* There are no microorganisms on planet earth able to break down glass materials, and since it takes thousands of years, **there is not a single glass bottle on the planet that has even come close to decomposing.**

The New Hampshire Department of Environmental Services estimates that it takes **1 million years** for a glass bottle to decompose. glass artifacts from glassmaking's beginnings , around 2000 B.C. in Egypt, still exist.[1]

***Warranty:*** *What type of warranty ( both material and workmanship ) is available through the glass block manufacturer?*

Glass products typically come with a ten-year warranty but longer warranties are available at added cost.[3] (Note that other common building materials – including stone and concrete – typically come with a one-year warranty for material and workmanship).

Dow warrants structural adhesives and pads on a project-specific basis (weather seals typically come with a 20-year warranty).

*(above)*
*'perfectly preserved' glass-ware recovered from a 2,000 year old shipwreck* [2]

*(left)*
*cast glass block after surviving a wildfire in California*

footnotes: **1**. Seattle Pi Education. "How Long Does It Take for a Glass Bottle to Degrade in a Landfill?" 29 Sept. 2016, education.seattlepi.com/long-glass-bottle-degrade-landfill-5235.html **2.** Smithsonian Magazine. "Perfectly Preserved Glassware Recovered From 2,000-Year-Old Shipwreck. *https://www.smithsonianmag.com/smart-news/glassware-2000-year-old-roman-shipwreck-180982615/* **3**. Viracon. "Viracon's Standard Ten-Year Limited Warranty." (*see appendix*)

2. Maintenance and Cleaning

***Cleaning Protocols:*** Recommended cleaning methods and products that won't damage the glass or its coatings.

Periodic cleanings (every 4-6 weeks) using ordinary water from the municipal supply will supplement the natural cleaning provided by rain water. Glass elements are scratch resistant, they change little over time and will not rust or fade. In addition, graffiti can be removed easily from glass without special tools or chemicals that might stain or change the appearance of other materials. [3]

A mild cleaning agent (dish soap) is recommended by cast glass fabricators to remove stains that don't come off via water spray cleaning. It is recommended to apply cleaning agent with a soft sponge and to dry with a squeegee or microfiber towel to prevent streaks caused from the cleaning solution drying on glass. Thus, textured surfaces do not adversely affect the cleanability of the glass.

***Surface Coatings:*** *Any coatings applied to resist graffiti, scratches, and other surface damages.*

To supplement periodic water spray cleaning or to minimize their required frequency, **hydrophilic coatings** can be applied to the surface of glass elements. Hydrophilic coatings are wettable, low-friction coatings that attract water and promote its absorption and distribution. When applied to a surface, hydrophilic coatings reduce surface tension, causing water to spread out evenly and form a thin layer, which helps to carry away dirt and impurities as the water runs off the surface. Some coatings that use metal oxides can even break down complex dirt and impurities using sunlight. The coating needs to be re-applied every 10 years. [1]

Vindico is an example of a hydrophilic coating.[2]

(Note: none of the glass fabricators in consideration deem these coatings necessary.)

footnotes: **1.** TU Delft, "Unveiling the third dimension of glass." *section 6.3.8 Maintenance*, https://journals.open.tudelft.nl/abe/article/view/4088
**2**. Vindico, "Vindico HP Product Specification." April 2011 (*see appendix*) **3.** Vitro, "Glass Technical Document TD-107." January 2018 (*see appendix*)
**4.** JHB Arts Consultants, "Qwalala General Care and Maintenance." (*see appendix*)

***Repairability:*** *Procedures for repairing or replacing damaged glass blocks?*

The glass elements are 15" thick and will be highly resistant to damage. Should a hairline crack occur, clear epoxy can be injected into the crack to prevent water and dirt from entering.

Scratches, chips or cracks in the cast glass elements can be repaired with epoxy resin cured with ultraviolet light (similar to the way scratches, chips or cracks in a windshield are repaired). See example here. The selected glass fabricator will create a video showing how scratches, chips, and cracks can be repaired and a locally-based glass technichian will be identified prior to installation of the memorial.

In the rare instance of a glass element needing replacement, the elements can be mechanically removed and replaced by locally applying high temperature to the adhesive. [1] A procedure for replacing a glass element will be included as part of the design process.

The glass fabricator, working under a maintenance agreement with the Foundation, would perform the scope of work in the event a repair is required. The memorial would have regular inspections (every 1-2 years) as part of this agreement.

*windsheild repair kit example*

footnotes: **1.** TU Delft, "Unveiling the third dimension of glass." *section 5.6.5 Impact and vandalism test*, https://journals.open.tudelft.nl/abe/article/view/4088

3. Safety and Comfort

***Breakage Patterns:*** *Details on how the glass breaks (e.g., shattering into small, blunt pieces vs. sharp shards).*

We have found no examples of cast borosilicate glass breaking; however, if soda-lime glass is any indication, the breakage would occur in the form of internal hairline cracks, not by breaking apart into pieces or shards.

Vandalism tests carried out on soda-lime glass blocks - which are much weaker than borosilicate glass - confirmed that glass cracked internally rather than breaking into shards, and the outer surface remained smooth. [1]

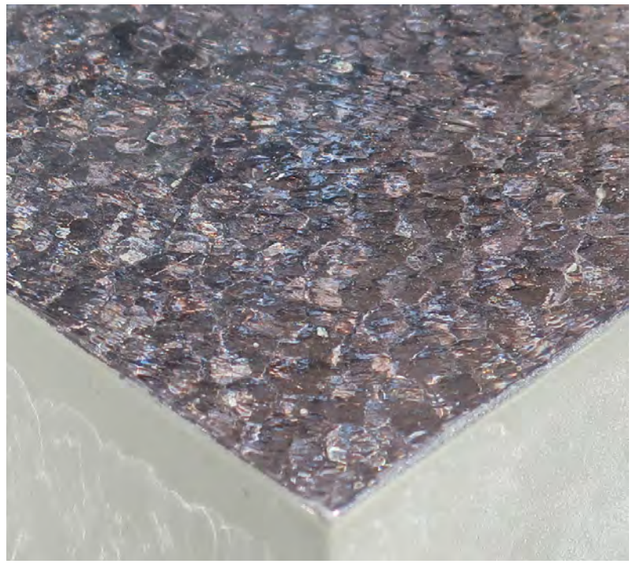
footnotes:

**1.** TU Delft, "Unveiling the third dimension of glass." *section 5.6.5 Impact and vandalism test*, https://journals.open.tudelft.nl/abe/article/view/4088

***Surface Treatment:*** *Anti-slip treatments for surfaces that will be walked or sat on. If surface treatments are used, provide performance characteristics and durability of these treatments*

Cast glass comes out of the mold with a naturally textured finish referred to as “mold struck”, which imparts a surface texture somewhere between orange peel and hammered copper. this texture is similar in roughness to flamed granite, which is commonly specified in outdoor paving applications. The anti-slip texture does not compromise the cleanability of the glass.

*granite - flamed finish*

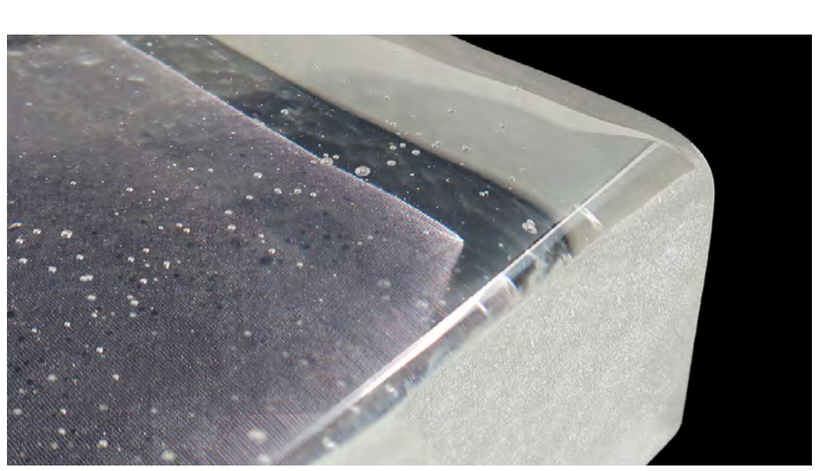


*cast glass - mold struck finish*

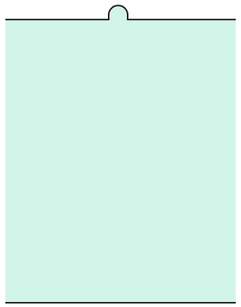
***Edge Treatments:*** *Methods used to smooth or round edges to prevent injuries, and to prevent skateboards to cause edge/corner damage?*

Cast glass has naturally rounded edges as a natural result of the casting process (*see image below*). The radiused edges also make the glass elements resistant to chipping.

Skateboard deterrent ridges similar to those commonly added to benches can be cast into the top surface of the glass, and skateboard deterrant strategies will be developed as part of the design process and tested on mockups prior to installation of the memorial.



*skateboard deterrent example*



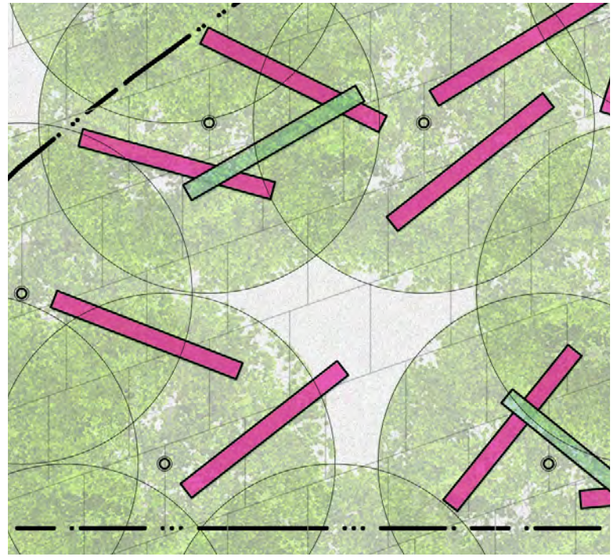
*cast glass section diagram with skateboard deterrent*

***Thermal Properties:*** *The surface temperatures of the glass when in extreme temperatures such as freezing weather or high heat. Do the glass blocks hold or radiate heat that would affect the temperature of enclosed areas such as the Remembrance Hall? Would the glass become very hot or cold to the touch?*

Glass does not reflect heat, but instead heat passes through glass, with only small amounts absorbed. this is why thermometers still use glass, and why the heat from the sun passes through a window and can be felt on the inside of a house.

See **table A** for thermal properties comparison of borosilicate glass, granite, marble, and stainless steel.

Appropriate testing will be done as part of the design process.



*seat-height glass elements (shown in pink) are located under shade trees for added human comfort*

***Comfort:*** *Assess the comfort of using glass benches, considering thermal conductivity and potential temperatures in varying weather conditions.*

Glass has a similar thermal conductivity to granite, and is over **10x** less conductive than stainless steel. (see **table A** for thermal properties comparison of borosilicate glass to other materials commonly used in memorials.)

4. Environmental Resistance

***Weather Resistance:*** *How the glass withstands exposure to sun, rain, snow, and temperature variations.*

Borosilicate glass is resistant to water, saline, acidic solutions, iodine, chlorine, bromine, and organic substances, even over long periods and temperatures above 212°F. Consequently, it is commonly used in laboratory applications. [1]

See **precedents section** for borosilicate glass structures that have been exposed to the weather.

***UV Resistance:*** Ability to resist degradation or discoloration due to UV exposure.

The majority of UV light passes through glass, but borosilicate glass has excellent thermal resistance, low UV radiation damage (low susceptibility towards solarization) and low degradation during high intensity radiation exposure. [2]

***Thermal Stability:*** Performance under extreme temperatures, both hot and cold.

Borosilicate glass elements can withstand temperatures ranging from **-320°F** to **+842°F** for long periods of time. [3]

They can withstand a temperature differential *within the element* of approximately 225°F before fracturing. [4]

footnotes: **1.** Präzisions Glas & Optik GmbH, "BOROFLOAT® 33 High-quality borosilicate glass from SCHOTT." May 2024. https://www.pgo-online.com/intl/borofloat.html **2.** Schott, "BOROFLOAT ® & Functional Coatings: A Union of Inspiration & Quality." (*see appendix*) **3.** Continental Trade, "Information Sheet: Borosilicate Glass 3.3 - DIN 7080". https://www.continentaltrade.com.pl/en/our-offer/technical-glass/types-of-materials/borosilicate-glass **4.** Schott, "BOROFLOAT® 33 Data Sheet." (*see appendix*)

5. Accessibility

***Accessibility:*** *Provide general information on how glass block benches and the glass block memorial design would align with ABAAS or ADA requirements for benches, aligning walkways, and walls.*

Per ABA and ADA requirements, ADA clear space is provided throughout the site alongside seat-height elements for wheelchair users. [1]

**802.1.2 Width.** A single wheelchair space shall be 36 inches (915 mm) wide minimum. Where two adjacent wheelchair spaces are provided, each wheelchair space shall be 33 inches (840 mm) wide minimum.

Figure 802.1.2

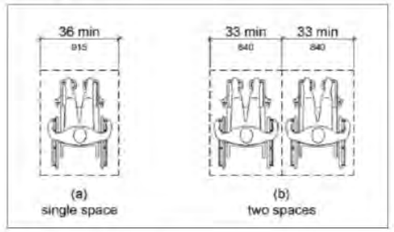
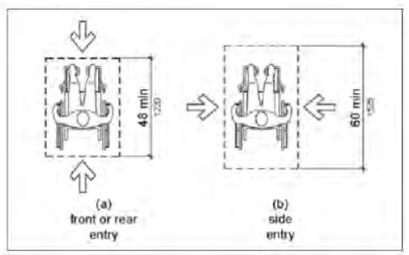
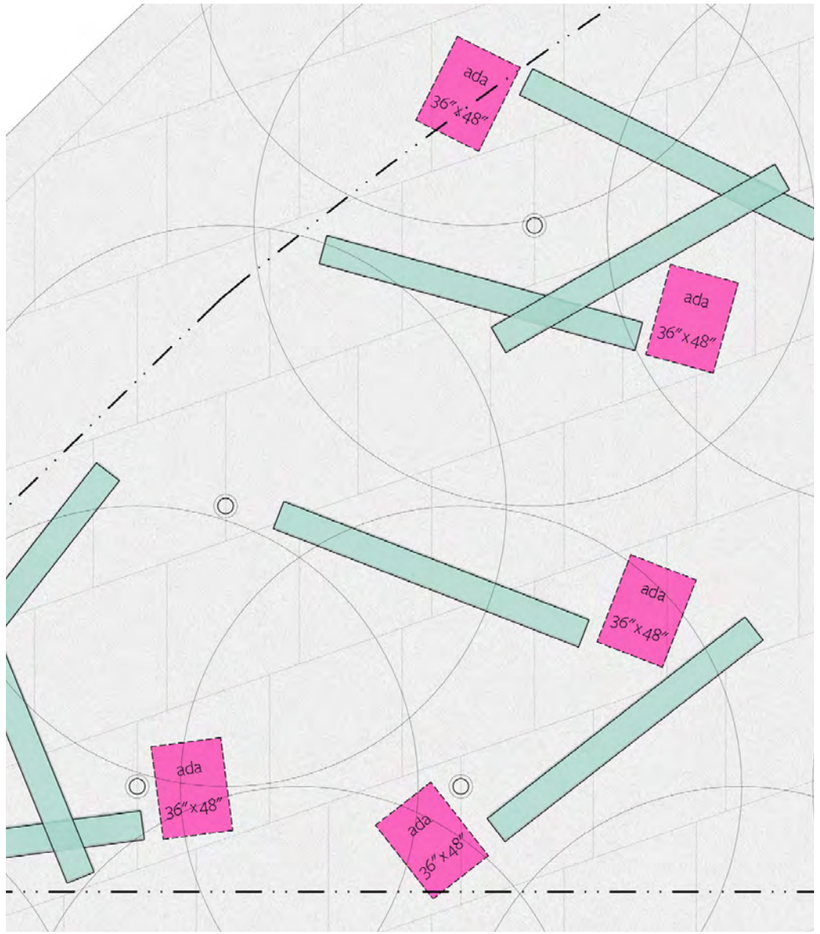



Figure 802.1.3

**802.1.3 Depth.** Where a wheelchair space can be entered from the front or rear, the wheelchair space shall be 48 inches (1220 mm) deep minimum. Where a wheelchair space can be entered only from the side, the wheelchair space shall be 60 inches (1525 mm) deep minimum.

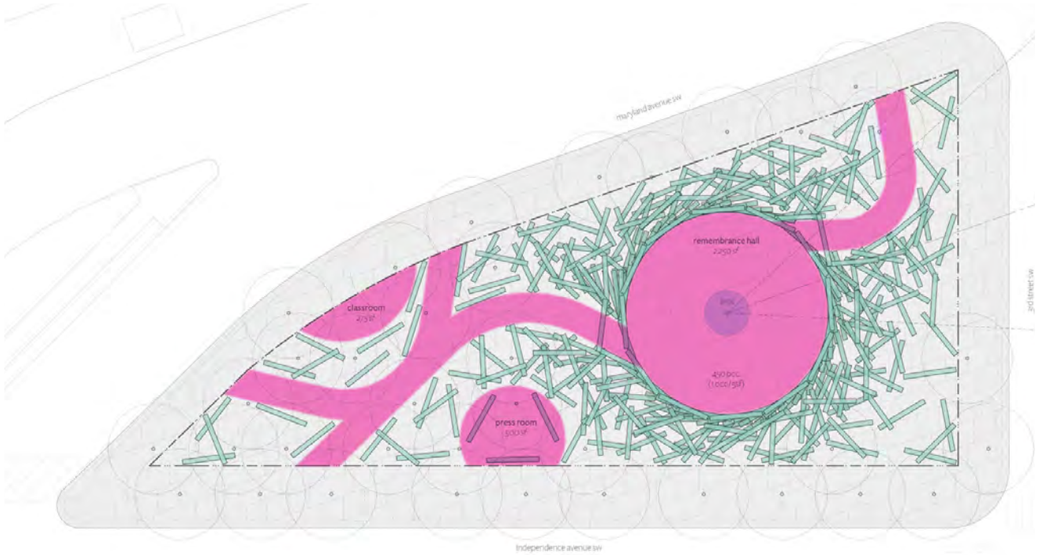



footnotes: **1.** landscapeforms, "ADA CRITERIA FOR BENCHES." https://journals.open.tudelft.nl/abe/article/view/4088 **2.** U.S. Access Board, "ABA Accessibility Standards." *403.5.1 Clear Width*, https://www.access-board.gov/aba/#aba-403_5_1 **3.** U.S. Access Board, "ADA Accessibility Standards." *403.5 Clearances*, https://www.access-board.gov/ada/guides/chapter-4-accessible-routes/#clearances

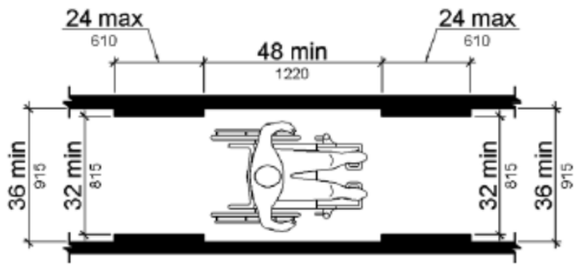
The visitor path maintains an **8'** clear width throughout (3' clear width is required per ADA and ABA[2][3]).

The walls of the visitor path are stacked such that no elements project into the clear width of the path.




*visitor path plan diagram*

**403.5.1 Clear Width.** Except as provided in 403.5.2 and 403.5.3, the clear width of walking surfaces shall be 36 inches (915 mm) minimum.



*visitor path section diagram*

footnotes: **1.** landscapeforms, "ADA CRITERIA FOR BENCHES." https://journals.open.tudelft.nl/abe/article/view/4088 **2.** U.S. Access Board, "ABA Accessibility Standards." *403.5.1 Clear Width*, https://www.access-board.gov/aba/#aba-403_5_1 **3.** U.S. Access Board, "ADA Accessibility Standards." *403.5 Clearances*, https://www.access-board.gov/ada/guides/chapter-4-accessible-routes/#clearances

Selected Precedents

**cast glass precedent A** atocha station memorial

| | |
|---|---|
| glass type: | borosilicate |
| year completed: | 2007 |
| location: | Madrid, Spain |
| designer: | Estudio FAM Arquitectura y Urbanismo |
| glass mfr: | Schott |
| glass size: | 11.81" x 7.87" x 2.75" bricks |
| glass quantity: | 15,600 bricks |
| glass texture: | smooth |
| structure: | UV-curing acrylate adhesive, glass brick walls rest on 200 elastomer pads supported by a steel ring above a post-tensioned concrete floor (see following page) |
| description: | 36' tall cylinder made up of 15,600 structural borosilicate glass bricks, adhesively bonded |
| link: | https://www.bellapart.com/paper/glass-monument-in-remembrance-of-the-terrorist-attacks-in-madrid-of-march-11-2004/ |

**cast glass precedent A** atocha station memorial

"As the massive glass elements experience high temperature differences (rain on a sun-heated glass block) and resulting high surface tensions, the 8,4 kg glass blocks are made out of **borosilicate glass**. Their low thermal expansion coefficient of 4,3 x 10-6 1/K is half of the value found in conventional soda-lime glass, which halves the thermal stresses in the blocks.

On site, the **glass blocks were glued together with an UV-curing acrylic adhesive**. The onecomponent product was created especially for this application by the manufacturer. Small and large samples were tested and verified with regard to the ageing resistance and long and short term resistance for different temperature levels.

...The structural analysis showed that deflections in the post-tensioned concrete flooring could create high shear forces in the glued joints of the 140 ton monument. In order to reduce this effect, the glass blocks are placed on a total of **200 elastomer pads** (160 mm x 100 mm x 45mm). This also compensates for differences in temperature strains between the glass and the substructure... **Vertical loads are transmitted by compression while horizontal loads are transmitted by friction.** Only a low-modulus silicone seal was installed between the glass blocks and the flanges of the steel ring in order to protect the elastomer pads from rain water and pollution.

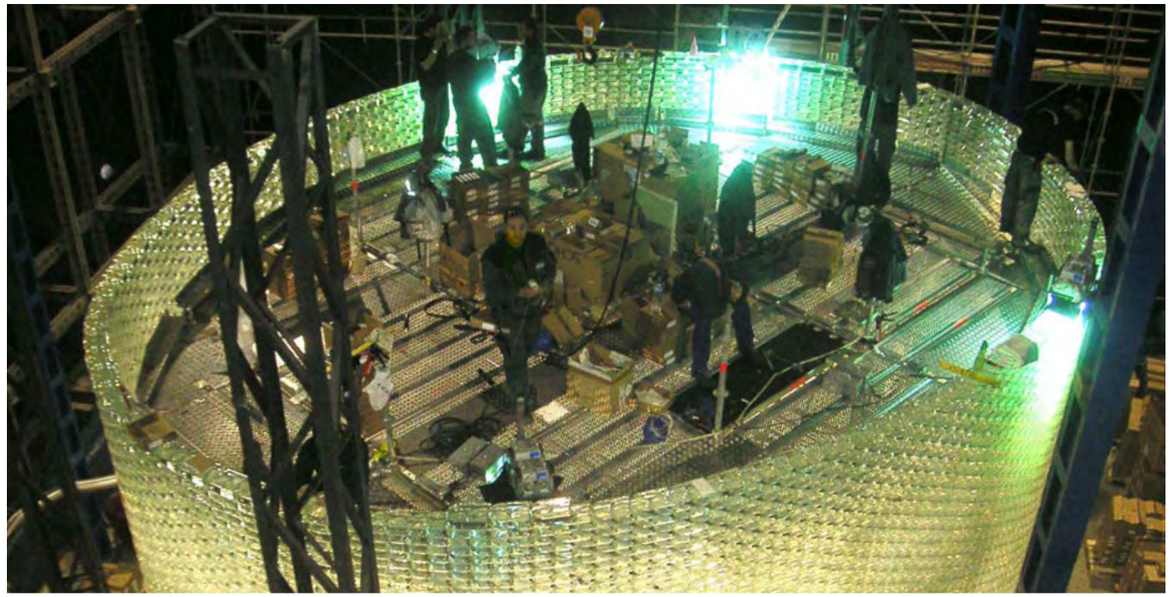
... a distribution of twelve heaps of glue per block with two different diameters was chosen... curing was guaranteed with **4 minutes of exposition to UVA radiation** with a wavelength of 320÷380 nm and an intensity between 15 and 30 mW/cm2. The intensity of all lamps was checked twice a day and light bulbs were replaced when necessary.

... Both horizontal and vertical joints between glass blocks were **sealed in order to guarantee water-tightness and to protect the adhesive from the adverse effects of weathering and pollution.** An ultra-transparent acid silicone was chosen for its aesthetical appearance and its compatibility with the adhesive."

sources of text and images:

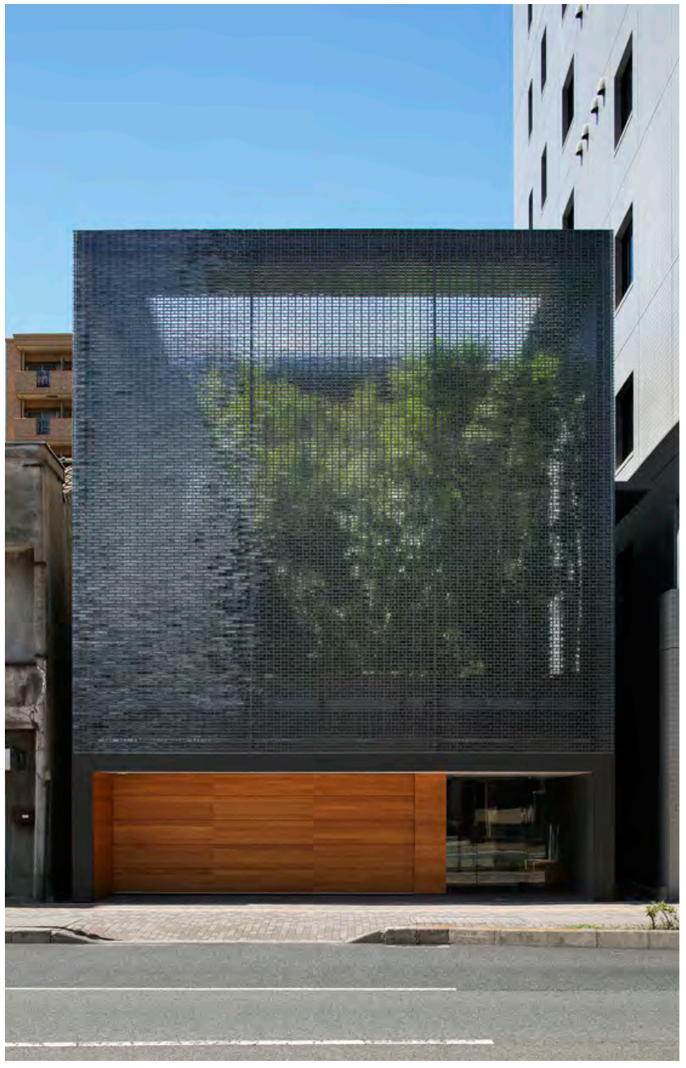
https://www.bellapart.com/paper/glass-monument-in-remembrance-of-the-terrorist-attacks-in-madrid-of-march-11-2004/

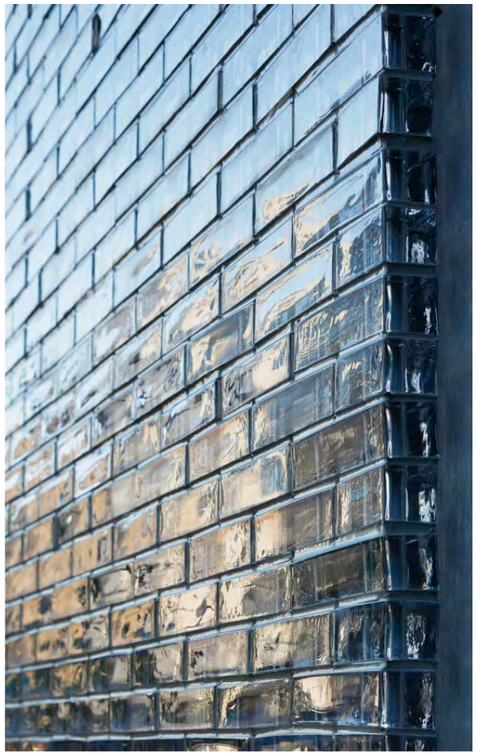
https://journals.open.tudelft.nl/abe/issue/view/726



**cast glass precedent B** optical house

| | |
|---|---|
| glass type: | borosilicate |
| year completed: | 2012 |
| location: | Hiroshima, Japan |
| designer: | Hiroshi Nakamura & NAP |
| glass size: | 9.25" x 2" x 2" bricks |
| glass quantity: | 6,000 bricks |
| glass texture: | smooth |
| structure: | stainless steel rods pass through holes in the glass bricks to resist lateral forces, the glass blocks carry their own weight, free of mortar |
| description: | 28' tall facade made up of 6,000 borosilicate glass bricks, chosen due to its increased optical qualities compared to soda-lime |
| interaction: | glass can be touched |
| link: | https://www.nakam.info/en/works/optical-glass-house/ |





**cast glass precedent C** mirage at apple park

| | |
|---|---|
| glass type: | soda-lime (containing sand from deserts around the world) |
| year completed: | 2023 |
| location: | Cupertino, California |
| designer: | Zeller & Moye (architect), Katie Paterson (artist) |
| glass mfr: | John Lewis Glass |
| glass size: | 6" diameter, 7'-4" tall cylinders (6'-7" above ground) |
| glass quantity: | 400 cylinders |
| glass texture: | smooth |
| description: | 400 cast glass cylinders form a 6'-7" high snaking wall, cylinders cast using sand collected from deserts worldwide |
| interaction: | glass can be touched |
| care: | The following cleaners may be used: Formula 409 Glass and Surface, Glass Plus, or Windex. To remove stubborn marks, wipe first with Acetone and a soft cloth, then follow with warm, soapy water. Dry thoroughly with a soft cloth. |
| link: | https://www.architecturalrecord.com/articles/16580-zeller-and-moyes-shimmering-glass-mirage-snakes-its-way-into-apple-park |

**cast glass precedent D** qwalala sculpture

| | |
|---|---|
| glass type: | soda-lime (25 different colors, adding color changes glass properties) |
| year completed: | 2017 |
| location: | Claremont McKenna College, California (originally Venice, Italy) |
| designer: | Pae White |
| glass mfr: | Poesía |
| glass size: | 6.25" x 6.25" x 12.5" bricks, 50 lbs each |
| glass quantity: | 3,000 bricks |
| glass texture: | smooth |
| structure: | shape optimized to limit shear stress, allowing flexible adhesive to be used (DOWSIL™ 993), glass bricks supported by steel plate foundation with structural silicon pad between the glass and steel |
| description: | 250' x 8' tall serpentine wall made up of 3,000 cast glass bricks |
| interaction: | glass can be touched and sat upon |
| care: | Rinse entire artwork with low-pressure filtered tap water to remove air borne dust and debris then wash with diluted Orvus paste cleaner mixed with filtered tap water. Beginning at the top of the Artwork, soak microfiber mitt in diluted soap water solution and wash surface. Do not allow soap mixture to dry on surfaces. Rinse with filtered tap water, allow to air dry. Spray microfiber cloth with diluted Isopropyl alcohol and wipe bricks to remove spotting. |
| link: | https://www.sbp.de/en/project/glass-sculpture-qwalala-by-pae-white/ |

**cast glass precedent E** crystal houses (chanel/hermes store)

| | |
|---|---|
| glass type: | low-iron soda-lime |
| year completed: | 2016 |
| location: | Amsterdam, Netherlands |
| designer: | MVRDV |
| glass mfr: | Poesía |
| glass size: | 8.25" x 8.25" x 2.5" (largest of three brick sizes) |
| glass quantity: | 7,500 bricks |
| glass texture: | smooth |
| structure: | UV-curing clear adhesive - Delo Photobond 4468 (see following page) |
| description: | 7,500 structural low-iron soda-lime glass bricks bonded with clear adhesive make a transparent masonry facade |
| interaction: | glass can be touched |
| link: | https://www.mvrdv.com/projects/240/crystal-houses |

**cast glass precedent E** crystal houses (chanel/hermes store)

"In principle, a glass masonry wall of the above mentioned dimensions is plausible thanks to the high compressive strength of glass and the 3-dimensional nature of the masonry wall that makes the construction buckling-resistant. Actually **one glass brick has sufficient compressive strength to carry the complete dead load of the façade**. The lateral stability of the glass façade was further enhanced through its geometry. Four buttresses, formed towards the interior of the façade by interlocking bricks, result in a continuous relief of increased rigidity. To obtain an all glass structural system a colourless adhesive should be applied for bonding the bricks."

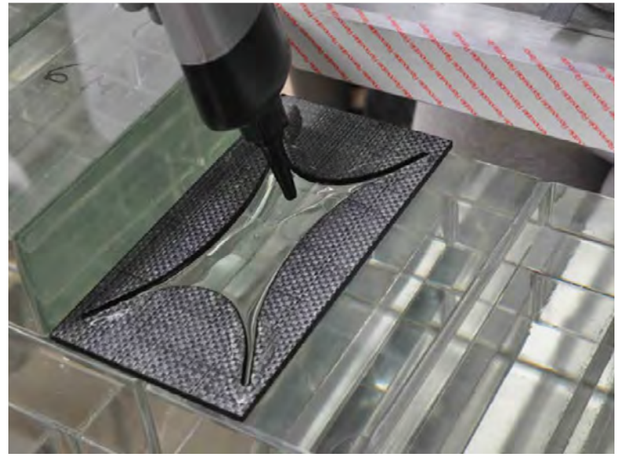
"...Structural tests and architectural mock-ups suggested the bonding of the complete contact surface between blocks. Through the uniform application of the adhesive both a homogeneous load distribution and maximized transparency are attained. To eliminate defects in the adhesive layer that would deeply affect the final visual result, a customized bonding method was developed, using custom-designed self-reinforced polypropylene forms for controlling the flow, spread and amount of the adhesive.

... the experimental results indicate that the structure presents a monolithic behaviour against the anticipated load, offering **compressive and flexural strength comparable to or better than the strength of typical B80 high performance concrete.**"

sources of text and images:

https://www.restructgroup-tudelft.nl/crystal-houses

https://journals.open.tudelft.nl/abe/issue/view/726



**cast glass precedent F** qaammat pavilion

| | |
|---|---|
| glass type: | soda-lime |
| year completed: | 2021 |
| location: | Sarfannguit, Greenland |
| designer: | Konstantin Arkitekter |
| glass mfr: | Wonderglass |
| glass size: | 9.45” × 4.33” × 2”bricks |
| glass quantity: | 1,100 bricks |
| glass texture: | mold struck finish |
| structure: | two different two-component adhesive able to withstand -35° C arctic temperatures (3M™ Scotch-Weld™ Polyurethane Adhesive DP610 for bottom rows, DOWSIL Experimental Fast Curing Adhesive for upper rows specifically formulated for this project), steel plate and rod substructure (see following page) |
| description: | 10’-6” x 6’-6” conical pavilion made up of structural soda-lime cast glass bricks, bonded with a two-component adhesive |
| interaction: | glass can be touched |
| link: | https://www.sbp.de/en/project/glass-sculpture-qwalala-by-pae-white/ |

**cast glass precedent F** qaammat pavilion

"[T]he location is just north of the arctic circle, implying that the adhesively-bonded pavilion should be able to withstand **temperatures as low as -35° C**. Hence, key for the successful construction of the Qaammat Pavilion is finding an adhesive that satisfies the structural and aesthetic requirements of the project, can withstand the extreme winter temperatures of the polar climate and can offer a simple, fast assembly process that spares the need of a specialized building crew and equipment.

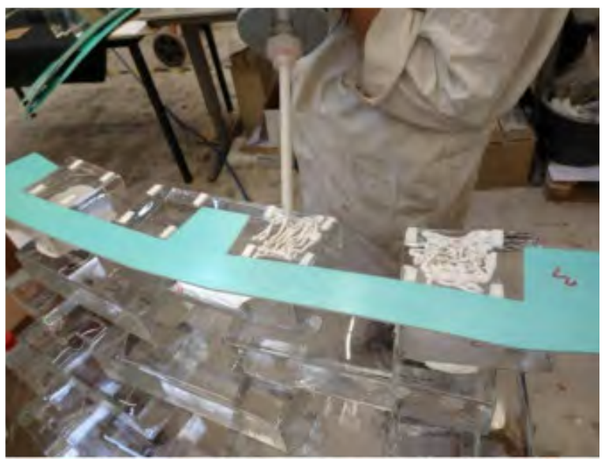
…**key performance criteria: a shear and tensile strength of ≥1 MPa and an operating temperature as low as -400C** in terms of structural performance; a clear or light in colour adhesive in terms of visual result; and a fast fixing (<30 min) and curing time (< 24hr) and a 1-3mm gap filling ability in terms of buildability…. here, two-component adhesives from the silicone and polyurethane families were considered the most suitable candidates."

note: soda-lime glass used in this structure

sources of text and images:

https://www.restructgroup-tudelft.nl/qaammat-pavillion

https://www.ncbi.nlm.nih.gov/pmc/articles/PMC8948317/



**cast glass precedent G** garden glass panels

| | |
|---|---|
| glass type: | soda-lime (custom product for milky, translucent quality) |
| location: | Dallas, Texas |
| designer: | Wayne Design Group |
| glass mfr: | Bullseye Glass |
| glass size: | 96" x 36" x 3" panels |
| glass quantity: | nine panels |
| glass texture: | mold struck finish |
| structure: | 2' tall steel pockets support glass panels |
| description: | nine monolithic glass slabs constructed of a custom-made glass product for a milky, translucent quality. Crushed iridized glasses were incorporated on the exterior for additional shimmer. |
| interaction: | glass can be touched |
| link: | https://studio.bullseyeglass.com/projects/garden-glass-panels/ |

**cast glass precedent H** oklahoma city national memorial

| | |
|---|---|
| glass type: | soda-lime |
| year completed: | 2000 |
| location: | Oklahoma City, Oklahoma |
| designer: | Hans & Torrey Butzer |
| glass mfr: | John Lewis Glass |
| glass quantity: | 168 chair bases |
| glass texture: | mold struck finish |
| structure: | single piece hollow pressed glass cubes |
| description: | 168 chairs consisting of hollow pressed glass cubes that are illuminated from inside with victims' names acid-etched on the front panel. |
| interaction: | glass can be touched |
| care: | The following cleaners may be used: Formula 409 Glass and Surface, Glass Plus, or Windex. To remove stubborn marks, wipe first with Acetone and a soft cloth, then follow with warm, soapy water. Dry thoroughly with a soft cloth. |
| link: | https://johnlewisglass.com/our-work/for-architects/oklahoma-city-memorial/ |

**cast glass precedent I** world financial center plaza

| | |
|---|---|
| glass type: | soda-lime |
| year completed: | 2007 |
| location: | New York City, New York |
| designer: | James Carpenter Design Associates, Inc. |
| glass mfr: | John Lewis Glass |
| glass quantity: | 256 castings |
| glass texture: | ribbed |
| structure: | stainless steel structure |
| description: | cast glass and stainless steel benches composed of 256 clear, ribbed castings. Provides approximately 200 linear feet of seating for the plaza. |
| interaction: | glass can be touched and sat upon |
| care: | The following cleaners may be used: Formula 409 Glass and Surface, Glass Plus, or Windex. To remove stubborn marks, wipe first with Acetone and a soft cloth, then follow with warm, soapy water. Dry thoroughly with a soft cloth. |
| link: | https://johnlewisglass.com/our-work/for-architects/battery-park-city/ |

**cast glass precedent J** the birth of venus sculpture

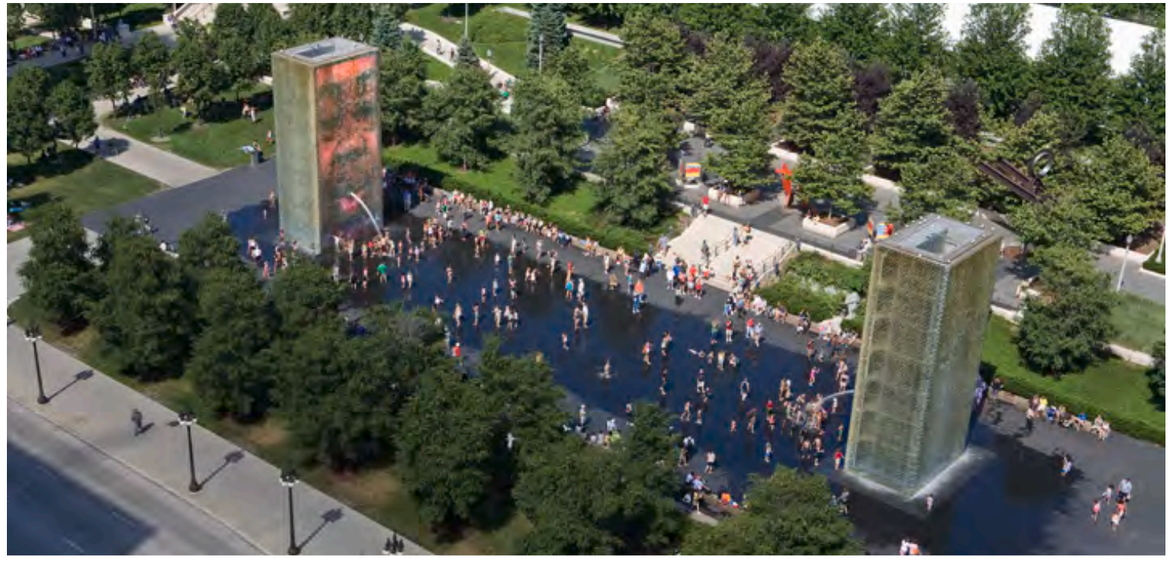
| | |
|---|---|
| glass type: | soda-lime |
| year completed: | 2006 |
| location: | Rome, New York |
| designer: | Lucia Warck Meister |
| glass mfr: | John Lewis Glass |
| glass size: | 16", 21", and 32" diameter spheres |
| glass quantity: | 16 cast glass spheres |
| glass texture: | mold struck finish |
| description: | outdoor sculpture composed of 16 cast glass spheres, originally shown at the Palm Beach, Florida Biennial |
| interaction: | glass can be touched and sat upon |
| care: | The following cleaners may be used: Formula 409 Glass and Surface, Glass Plus, or Windex. To remove stubborn marks, wipe first with Acetone and a soft cloth, then follow with warm, soapy water. Dry thoroughly with a soft cloth. |
| link: | https://ivisgallery.com/en/Artist/the-birth-of-venus/ |

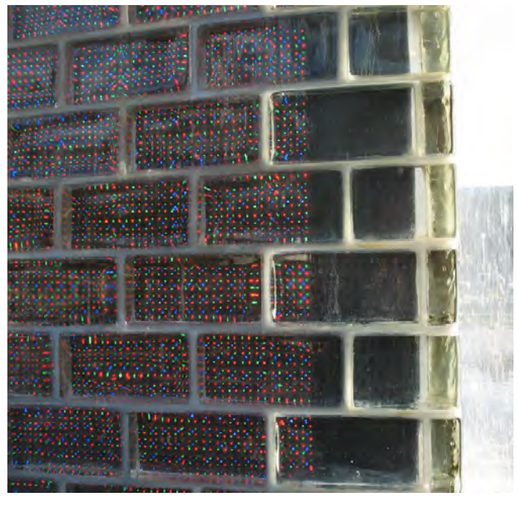
**cast glass precedent K** one shell plaza

| | |
|---|---|
| glass type: | soda-lime |
| year completed: | 2013 |
| location: | Houston, Texas |
| designer: | Jacobs Engineering Company |
| glass mfr: | John Lewis Glass |
| glass size: | 40.5" x 17" x 12" bollard cap |
| glass quantity: | 26 cast glass bollard caps |
| glass texture: | smooth exterior, sandblasted interior |
| description: | 26 internally lit cast glass bollard caps located in a public plaza |
| interaction: | glass can be touched |
| care: | The following cleaners may be used: Formula 409 Glass and Surface, Glass Plus, or Windex. To remove stubborn marks, wipe first with Acetone and a soft cloth, then follow with warm, soapy water. Dry thoroughly with a soft cloth. |
| link: | https://johnlewisglass.com/our-work/for-architects/one-shell-plaza/ |

**cast glass precedent L** crown fountain

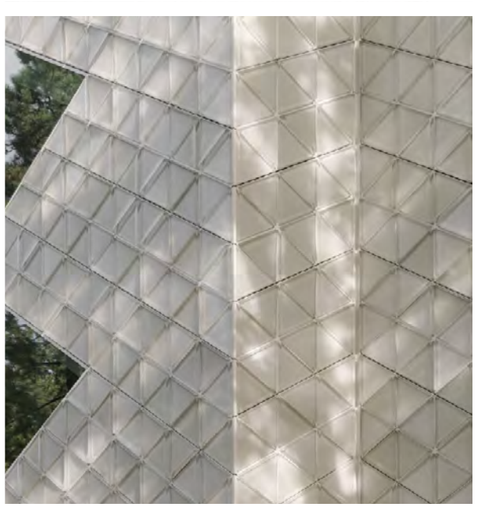
| | |
|---|---|
| glass type: | low-iron soda-lime |
| year completed: | 2004 |
| location: | Chicago, Illinois |
| designer: | Jaume Plensa, Krueck & Sexton Architects |
| glass mfr: | L. E. Smith Glass Co. |
| glass size: | 5" x 10" x 2" bricks |
| glass quantity: | 22,500 bricks |
| glass texture: | smooth |
| structure: | pre-assembled glass block grates connected to a stainless steel internal frame |
| description: | public fountain comprising two 50' x 23' x 16' towers made up of 22,500 low-iron soda-lime glass bricks supported by a stainless steel substructure |
| interaction: | glass can be touched |
| link: | https://www.archdaily.com/109201/the-crown-fountain-krueck-sexton-architects |





**cast glass precedent M** helvetia headquarters

| | |
|---|---|
| glass type: | soda-lime |
| year completed: | to be completed 2024 |
| location: | Basel, Switzerland |
| designer: | Herzog & de Meuron |
| glass mfr: | Poesía |
| glass quantity: | 24,000 tiles |
| glass texture: | smooth |
| description: | two towers clad in 24,000 cast glass curved triangular tiles |
| link: | https://www.herzogdemeuron.com/projects/419-helvetia-campus-basel/ |



## supplemental glass precedents

Though an ancient material, glass technology is advancing rapidly with new uses and applications growing by the day. Below are some notable projects which demonstrate recent advances in glass technology.

1 **louvre glass pyramid** paris, france 1989

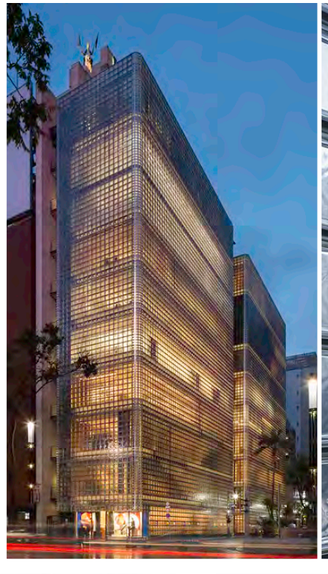
2 **maison hermes** tokyo, japan 2001

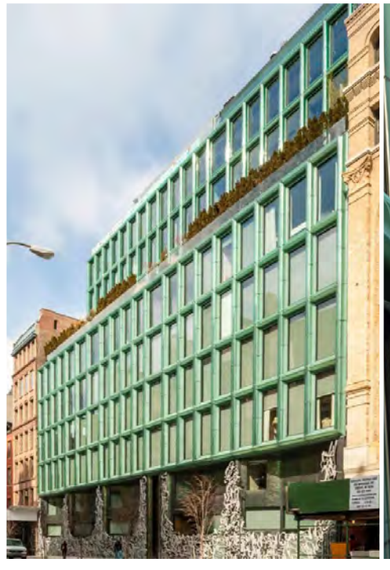
3 **prada building aoyama** tokyo, japan 2003

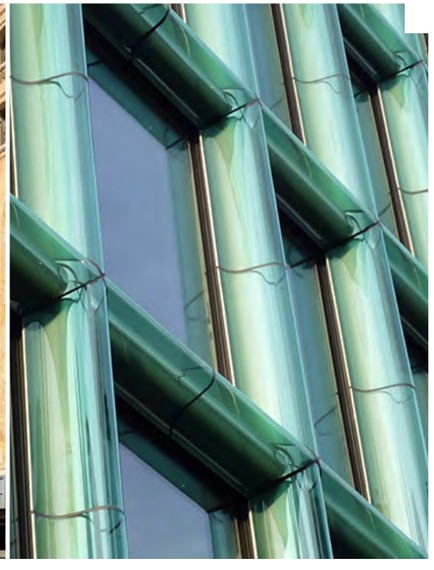
4 **apple store fifth avenue** new york city, new york 2006

5 **40 bond st** new york city, new york 2007

6 **national center for the performing arts** beijing, china 2007







## supplemental glass precedents

7 **iac building** new york city, new york 2007

8 **willis tower observation platform** chicago, illinois 2009

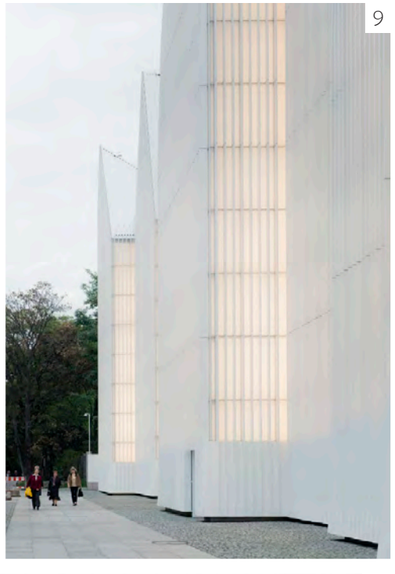
9 **philharmonic hall szczecin** szczecin, poland 2014

10 **ports 1961** shanghai, china 2015

11 **vidre slide** installation 2016

12 **elbphilharmonie** hamburg, germany 2017

9



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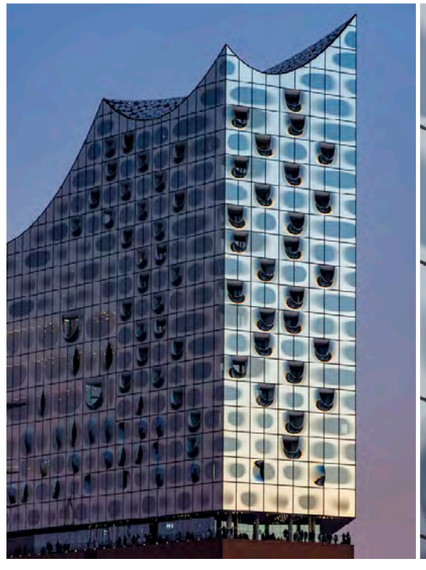
11



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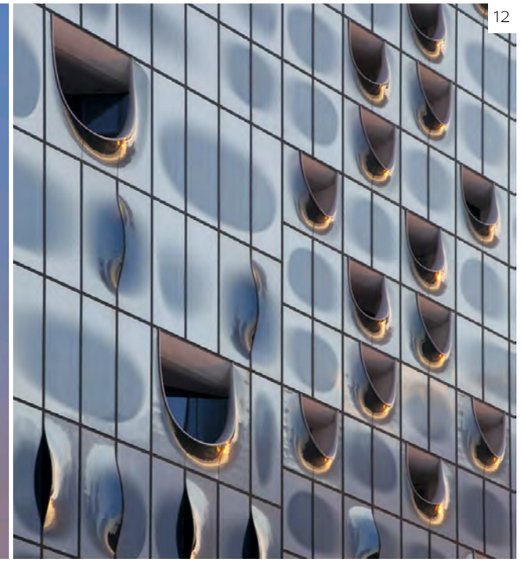


## supplemental glass precedents

13 **K 11** hong kong 2017

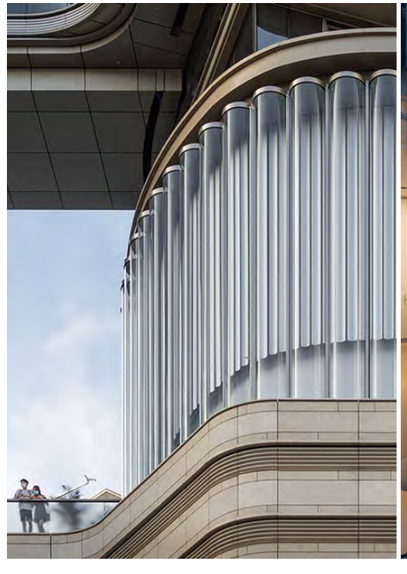
14 **amazon spheres** seattle, washington 2018

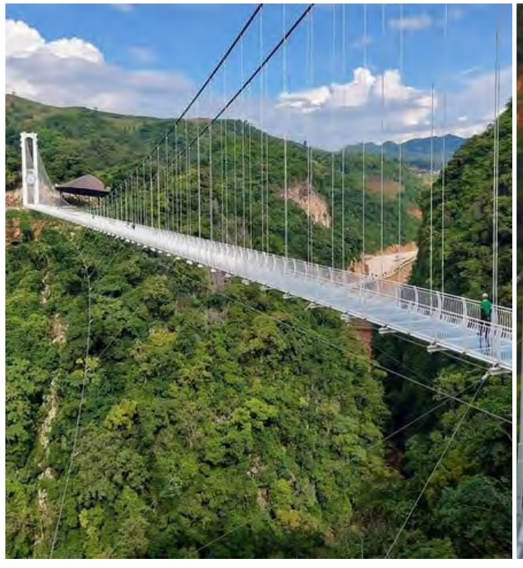
15 **la samaritaine store** paris, france 2021

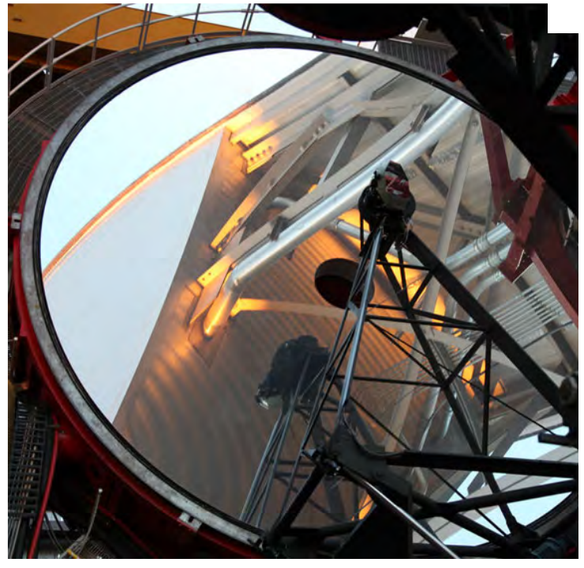
16 **taikang headquarters** beijing, china 2021 (world's largest installed glass panes, 52' tall)

17 **bach long bridge** son la, vietnam 2022 (world's longest glass bridge , 2,000')

18 **giant magellan telescope mirrors** atacama desert, chile 2030 (est. completion)







# Appendix

# SCHOTT BOROFLOAT® 33

The versatile floated borosilicate glass - with an infinite number of applications

SCHOTT
glass made of ideas

## ▶ Summary


3 Floated Borosilicate Glass from SCHOTT

5 Product Description

6 Forms Supplied

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12 Mechanical Properties

12 Thermal Properties

17 Chemical Properties

19 Optical Properties

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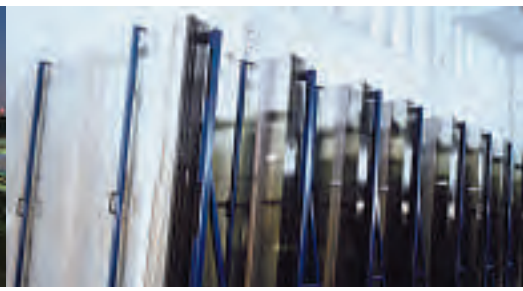
30 Fitting

30 Cleaning



# SCHOTT BOROFLOAT® 33

## Floated Borosilicate Glass from SCHOTT

BOROFLOAT® 33 is a high quality borosilicate glass with outstanding properties for a wide-range of applications.

This unique special float glass is manufactured by SCHOTT Technical Glass Solutions GmbH using the Microfloat process and the latest technology. This technology also results in a homogeneous material that has an excellent mirror-like surface, a high degree of flatness and an outstanding optical quality.

BOROFLOAT® 33 is a clear and transparent colourless glass. Its excellent transmission and its very weak fluorescence intensities over the entire light spectrum make BOROFLOAT® 33 ideal for a wide range of applications in optics, optoelectronics, photonics and analytical equipment.

Its low thermal expansion, its high thermal shock resistance and its ability to withstand temperatures up to 450°C for long periods make BOROFLOAT® 33 a good choice for applications which call for good temperature stability (e.g. internal panels in pyrolytic self-cleaning ovens and over plates for high-power floodlights).

BOROFLOAT® 33 is highly resistant to attack by water, strong acids, alkalis as well as organic substances. Therefore it is particularly suitable for applications in the chemical industry such as sight glasses for reaction vessels and fittings.

Another interesting field of application is in medical and analytical technology. Measurements are hardly influenced by the glass receptacle because the exposure to water and acids results only in the leaching out of small amounts of ions from the glass.

BOROFLOAT® 33 has a lower density than soda lime float glass. It makes it possible to construct lightweight laminated glass systems (e.g. bulletproof glass).

BOROFLOAT® 33 has proven itself in many traditional applications and, today, there is an increasing area of usage in new and technically sophisticated special glass applications such as biotechnology, microelectronics and photovoltaics.

## *Fields of Application of BOROFLOAT® 33*

Its special physical and chemical properties make BOROFLOAT® 33 a truly versatile performer with a broad range of uses:

- Home Appliances (interior oven doors, fittings in microwave appliances, window panels for fireplaces)
- Environmental engineering, chemical industry (resistant linings and sight glasses for reaction vessels, microfluidic systems)
- Lighting (protective panels for spotlights and high-power floodlights)
- Photovoltaics (glass for solar collectors)
- Precision engineering, optics (optical filters and mirrors etc.)
- Medical technology, biotechnology (slides, biochips, titration plates, DNA sequencers, microfluidic systems)
- Semiconductor engineering, electronics, sensors (wafers, display glass)
- Safety (bulletproof glazing)

The quality of BOROFLOAT® 33 is ensured by our quality assurance system according to the requirements of the DIN ISO 9001.

# Product Description

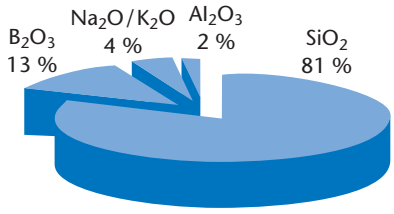
BOROFLOAT® 33 is a borosilicate glass type 3.3 as specified in the international standard ISO 3585 and EN 1748 T1. BOROFLOAT® 33 products meet most international standards, for example the German, British, American and French standards.

The structural characteristics and the material's purity grade (low content of polyvalent ions) of BOROFLOAT® 33 results in an overall high transmission of ultraviolet, visible and infrared wavelengths.

Thanks to its low alkali content, BOROFLOAT® 33 works as a good electric insulator.

Due to its high boron content, BOROFLOAT® 33 can be used as a neutron absorber glass in nuclear energy applications.

***Chemical Composition***




BOROFLOAT® 33 is environmentally friendly and made of natural raw materials. The glass can be recycled several times and disposed of without difficulties.

***Environmental Safety/ Ecological Reliability***

# Forms Supplied

## *Panel Thickness*

BOROFLOAT® 33 is offered in the following thicknesses and tolerances, in mm (in.):

| Thickness | | Tolerance | |
|---|---|---|---|
| 1.10 | (0.043) | ± 0.1 | (0.004) |
| 1.75 | (0.069) | ± 0.1 | (0.004) |
| 2.00 | (0.079) | ± 0.2 | (0.008) |
| 2.25 | (0.089) | ± 0.2 | (0.008) |
| 2.75 | (0.108) | ± 0.2 | (0.008) |
| 3.30 | (0.130) | ± 0.2 | (0.008) |
| 3.80 | (0.150) | ± 0.2 | (0.008) |
| 5.00 | (0.197) | ± 0.2 | (0.008) |
| 5.50 | (0.216) | ± 0.2 | (0.008) |
| 6.50 | (0.256) | ± 0.2 | (0.008) |
| 7.50 | (0.295) | ± 0.3 | (0.012) |
| 8.00 | (0.315) | ± 0.3 | (0.012) |
| 9.00 | (0.354) | ± 0.3 | (0.012) |
| 11.00 | (0.433) | ± 0.3 | (0.012) |
| 13.00 | (0.512) | ± 0.5 | (0.020) |
| 15.00 | (0.590) | ± 0.5 | (0.020) |
| 16.00 | (0.630) | ± 0.5 | (0.020) |
| 18.00 | (0.708) | ± 0.5 | (0.020) |
| 19.00 | (0.748) | ± 0.5 | (0.020) |
| 21.00 | (0.827) | ± 0.7 | (0.027) |
| 25.40 | (1.000) | ± 1.0 | (0.040) |

Panel thickness is continuously measured during production using laser thickness measuring equipment. Other nominal thicknesses and tolerances are supplied on request.

# Forms Supplied

*Sizes* ◀

| Standard Sizes | Thickness |
|---|---|
| 1150 x 850 mm² (45.3 x 33.5 in.²) | 0.7–25.4 mm (0.027 to 1.000 in.) |
| 1700 x 1300 mm² (66.9 x 51.2 in.²) | 16.0–21.0 mm (0.630 to 0.827 in.) |
| 2300 x 1700 mm² (90.5 x 66.9 in.²) | 3.3–15.0 mm (0.130 to 0.590 in.) |

| | | |
|---|---|---|
| Min. size for stock sizes | 700 x 575 mm² | (28 x 23 in.²) |
| Max. size for stock sizes | 3000 x 2300 mm² | (120 x 92 in.²) |
| | [for 5.5 to 9 mm (0.216–0.354 in.) thickness] | |

***We will be happy to provide other sizes upon request.***

*Processing and Finishing* ◀

Our BOROFLOAT® 33 product range is complemented by a wide variety of processing and finishing possibilities:

**Processing:**

1.1 Cutting (including water jet and laser)
1.2 Edge finish (arrissed, bevelled, ground or polished edges) and corner finish (dubbed or rounded corners)
1.3 Drilling (including ultrasonic)

**Finishing:**

2.1 Coating
2.2 Thermal semi-toughening
2.3 Printing, sandblasting/matte finishing
2.4 Surface polishing
2.5 Bending
2.6 Subsurface laser engraving

# Forms Supplied

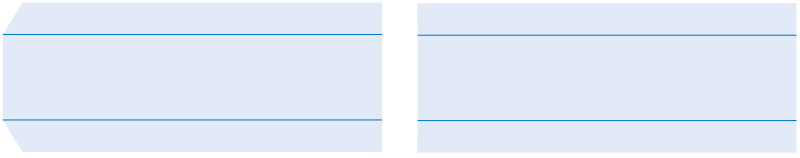
## *Processing*

1.1 **Cutting:** BOROFLOAT® 33 can be cut to size within the standard sizes. The minimum dimensions of cut-to-size sheets will be supplied on request.

1.2 **Edge and corner finish:** The standard edge finish for cut-to-size panels is RK2 following DIN 1249 T 11, see sketch 1.2.a and prEN 13024 – 1, see sketch 1.2.b.
Other edge forms (ground and polished) on request.



*1.2.a: Rounded edge, flat-arrissed (RK2)*



*1.2.b: Ground edge*

The standard corner working is dubbed. Sheet can also be supplied on request with corner radii.

1.3 **Drilling:** BOROFLOAT® 33 can be supplied with boreholes as agreed.

**Diameter of boreholes**

BOROFLOAT® 33 can be supplied with boreholes of Ø 2 mm and larger.
BOROFLOAT® 33 with cut-outs on request.

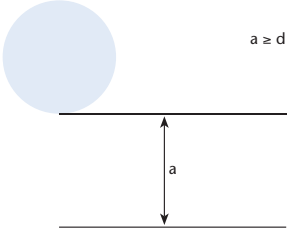
**Limitations on the position of boreholes**

Limitations on the position of boreholes in relation to the edges and corners of the sheet and also to each other are generally dependent on:

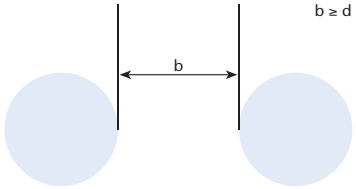
- the nominal thickness of the glass (*d*),
- the sheet dimensions (B, H),
- the diameter of the hole (Ø)
- the shape of sheet.

The following limitations on the position of holes apply to sheets with a maximum of four holes. If the sheet has a different hole configuration, other limitations may apply. Details on request.

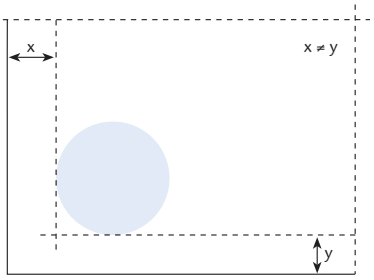
1. The distance *a* between the edge of the hole and the edge of the glass should not be less than the thickness of the glass *d*.




2. The distance *b* between the edges of the various holes should also not be less than *d*.



3. Depending on the position of the holes in relation to the corner of the glass it is possible for the distance to the two sides edges to be different. Details on request.




4. Permitted borehole position deviation:
Deviation of borehole center: ± 1.5 mm.

# Forms Supplied



2.1 **Coating**

Coating with composite materials can be used to vary the specific properties of BOROFLOAT® to match the requirements of a particular application. This increases its functionality:

**BOROFLOAT® M with reflective coating**

The application of appropriate interference layers (e.g. metal oxides) results in the part of the radiation of visible light responsible for the reflection being semireflected particularly well (reflection wanted). Due to the reflection effect e.g. appliance components located behind the glass can be concealed. Typical applications of this nature are to be found in the lighting industry.

**BOROFLOAT® AR with anti-reflective coating**

The application of appropriate interference layers results in the part of the radiation responsible for the reflection being reduced (reflection and mirror effect largely prevented). There are applications for BOROFLOAT® AR everywhere where a glass is required without any irritating reflections.

Coated BOROFLOAT® 33 is supplied in the 3.3 mm thickness and 1150 x 850 mm sheet size. We will be happy to provide information about other thickness and sizes plus information about other coatings upon request.

2.2 **Thermal semi-toughening:**

The resistance of BOROFLOAT® 33 to thermal and mechanical loads is improved by thermal semi-toughening.

Thermal semi-toughening is possible in the thicknesses from 3.3 to 15 mm. The maximum sheet size is 3000 x 1800 mm and the minimum edge length is 300 mm. We will be happy to provide information about thickness and sizes at any time on request.

2.3–2.6 We will be happy to provide detailed information on request.

# Technical Properties

The values below are generally applicable basic data for BOROFLOAT® 33. Unless stated different these are guide figures according to DIN 55350 T12. However, they also apply to the coated versions (BOROFLOAT® AR and BOROFLOAT® M) except for the transmission data (see Optical Properties, pages 19 ff).

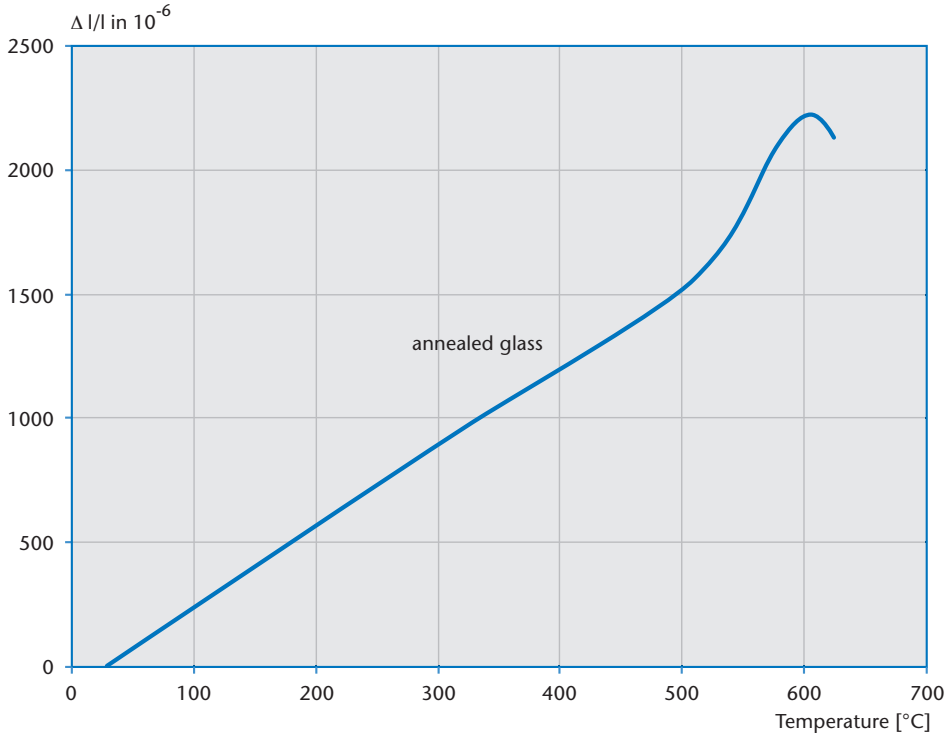
# Mechanical Properties

| | | | |
|---|---|---|---|
| Density (25°C) | $\rho$ | 2.2 g/cm³ | |
| Young's Modulus | E | 64 kN/mm² | (to DIN 13316) |
| Poisson's Ratio | $\mu$ | 0.2 | (to DIN 13316) |
| Knoop Hardness | $HK_{0.1/20}$ | 480 | (to ISO 9385) |
| Bending strength | $\sigma$ | 25 MPa | (to DIN 52292 T1) |
| Impact resistance | The impact resistance of BOROFLOAT® 33 depends on the way it is fitted, the size and thickness of the panel, the type of impact involed, presence of drill holes and their arrangement as well as other parameters. | | |

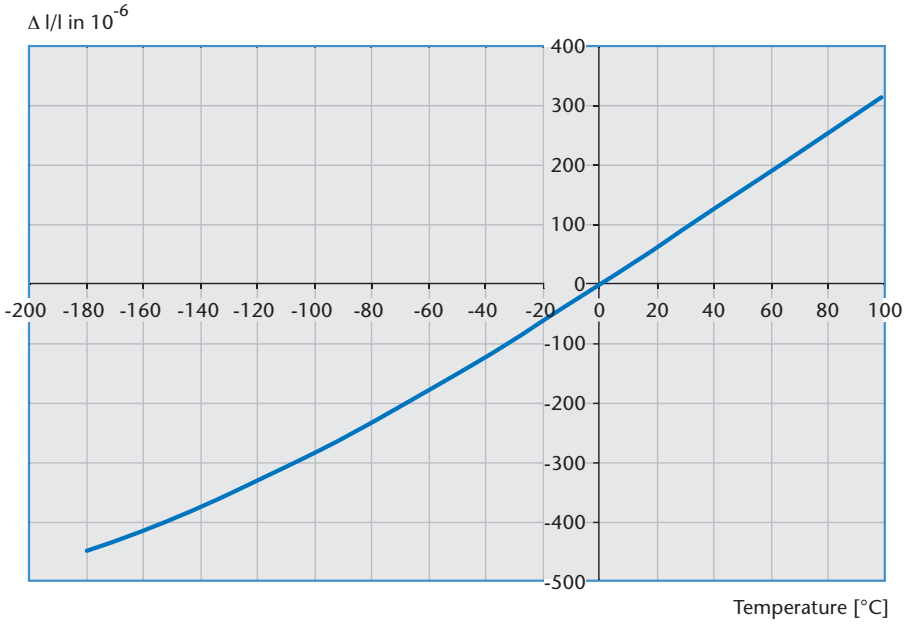
# Thermal Properties

| | | |
|---|---|---|
| Coefficient of Linear Thermal Expansion (C.T.E.) | $\alpha_{(20–300\ °C)}$ | $3.25 \times 10^{-6}\ K^{-1}$ (to ISO 7991) |
| Specific Heat Capacity | $c_{p\ (20–100\ °C)}$ | $0.83\ KJ \times (kg \times K)^{-1}$ |
| Thermal Conductivity | $\lambda_{(90\ °C)}$ | $1.2\ W \times (m \times K)^{-1}$ |

# Thermal Properties



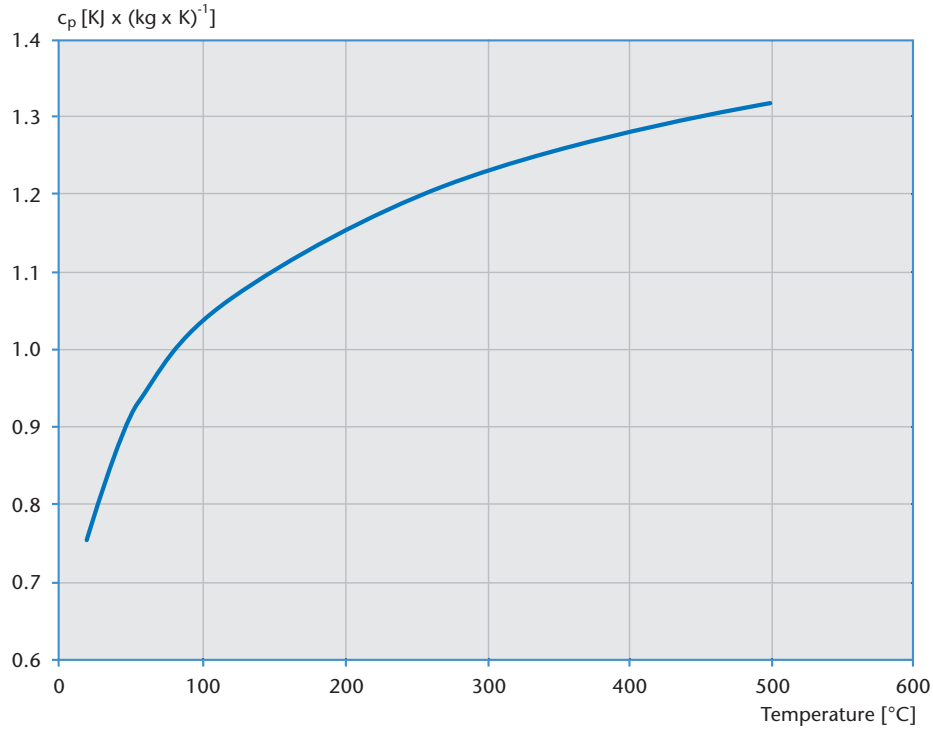

***BOROFLOAT® 33 –***
***Thermal Expansion***



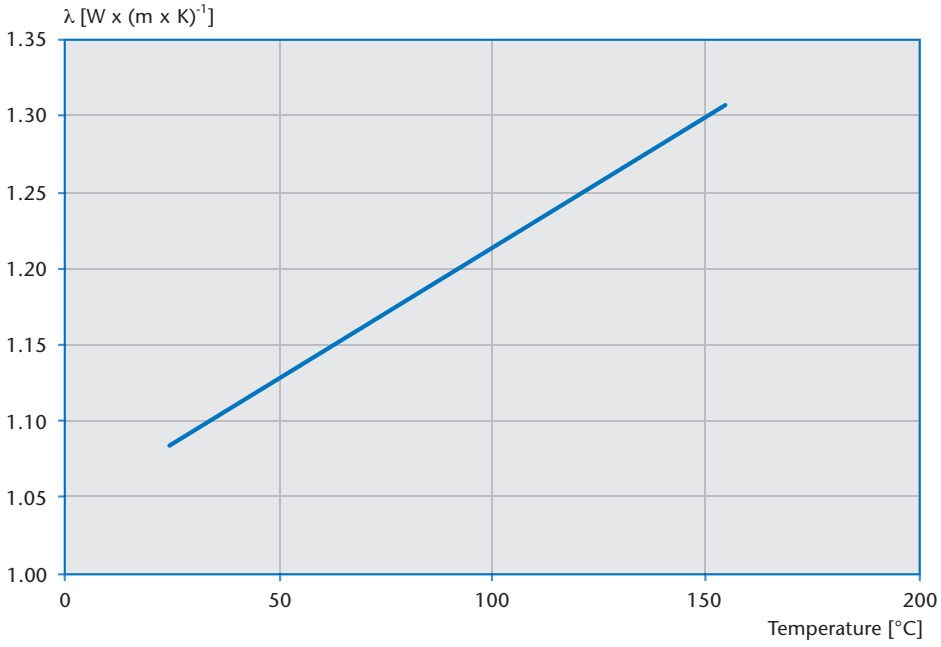

***BOROFLOAT® 33 –***
***Behavior in the Cryogenic***
***Temperature Range***

# Thermal Properties

▶ ***BOROFLOAT® 33 –***
***Specific Heat Capacity ($c_p$)***




▶ ***BOROFLOAT® 33 –***
***Thermal Conductivity ($\lambda$)***



# Thermal Properties

## *Maximum Operating Temperature*

| | | $T_{max}$ |
|---|---|---|
| For short-term usage | < 10 h | 500 °C |
| For long-term usage | ≥ 10 h | 450 °C |

The maximum temperatures in use indicated apply only if the following RTG and RTS values are observed at the same time.

## *Resistance to Thermal Gradients (RTG)*

The RTG value characterizes the ability of a glass type to withstand a specific temperature difference between the hot center and the cold edges of a panel.

| | RTG |
|---|---|
| < 1 hour | 110 K |
| 1–100 hours | 90 K |
| > 100 hours | 80 K |

**Test method:** Plates of approximately 25 x 25 $cm^2$ (10 x 10 $in.^2$) are heated in the center to a defined temperature, and the edge of the plate is kept at room temperature, at which ≤ 5 % of the samples suffer breakage.
The plates are abraded with 40 grit sandpaper prior to the test. This simulates extreme surface damage which may occur in operation.

## *Resistance to Thermal Shock (RTS)*

The RTS value characterizes the ability of a glass panel to withstand a sudden temperature decrease.

| Glass Thickness | RTS |
|---|---|
| ≤ 3.8 mm | 175 K |
| 5.0 – 5.5 mm | 160 K |
| 6.5 – 15.0 mm | 150 K |
| > 15.0 mm | 125 K |

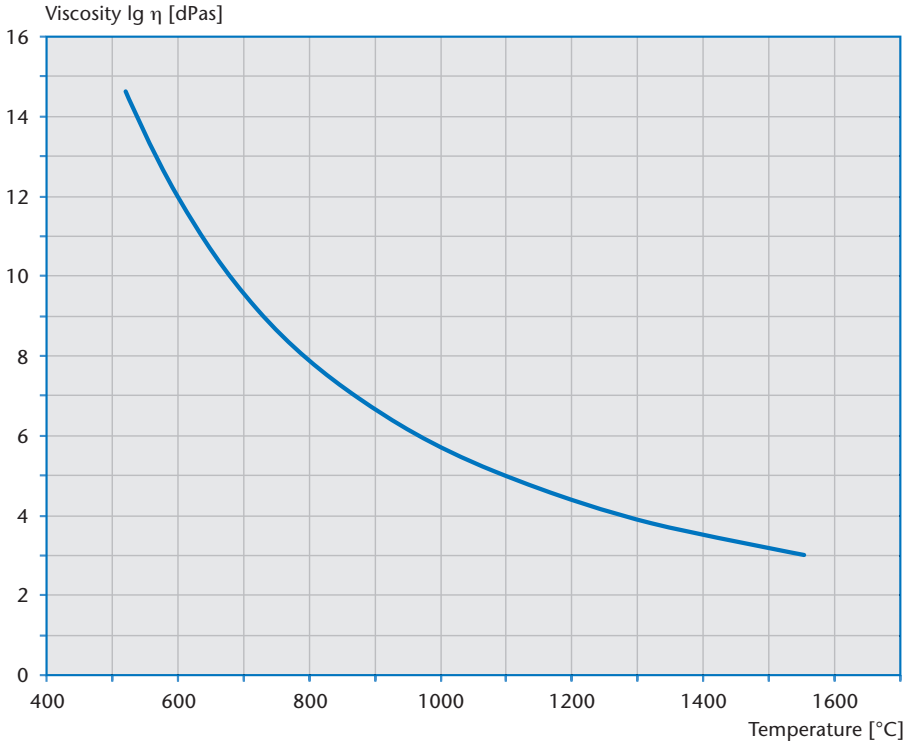
**Test method:** Plates of approximately 20 x 20 $cm^2$ (8 x 8 $in.^2$) are heated in an oven with recirculated air and then doused in the center with 50 ml (3.3 oz.) of room temperature water, at which ≤ 5 % of the samples suffer breakage.
The plates are abraded before heating with 220 grit sandpaper to simulate typical surface condition during practical use.

# Thermal Properties

▶ ***Viscosity of Borosilicate Glasses***

| Viscosity η | | | |
|---|---|---|---|
| Working Point | $10^4$ | dPas | 1270 °C |
| Softening Point | $10^{7.6}$ | dPas | 820 °C |
| Annealing Point | $10^{13}$ | dPas | 560 °C |
| Strain Point | $10^{14.5}$ | dPas | 518 °C |
| Transformation Temperature ($T_g$) | | | 525 °C |

▶ ***BOROFLOAT® 33 – Temperature Dependence of the Viscosity (η)***



# Chemical Properties

| | | |
|---|---|---|
| Hydrolytic resistance | according ISO 719 / DIN 12 111 | HGB 1 |
| | according ISO 720 | HGA 1 |
| Acid resistance | according ISO 1776 / DIN 12 116 | 1 |
| Alkali resistance | according ISO 695 / DIN 52 322 | A 2 |

***Chemical Resistance of BOROFLOAT® 33 to Selected Reagents***

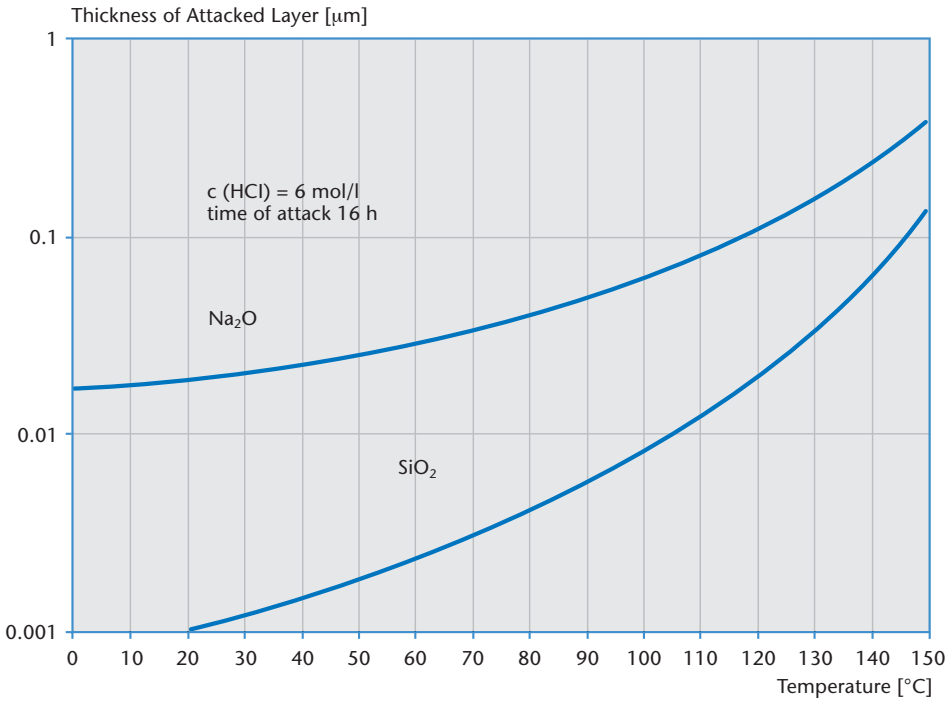
| Reagent | Weight Loss [mg/cm²] | Visual Inspection Results/ Appearance |
|---|---|---|
| 24 h at 95 °C | | |
| 5 Vol.% HCl | < 0.01 | unchanged |
| 0.02 n $H_2S0_4$ | < 0.01 | unchanged |
| $H_20$ | < 0.01 | unchanged |
| 6 h at 95 °C | | |
| 5% NaOH | 1.1 | white stains |
| 0.02 n NaOH | 0.16 | white haze |
| 0.02 n $Na_2CO_3$ | 0.16 | unchanged |
| 20 min at 23 °C | | |
| 10% HF | 1.1 | stained white haze |
| 10% $NH_4F$ x HF | 0.14 | unchanged |

***Tin Residues***

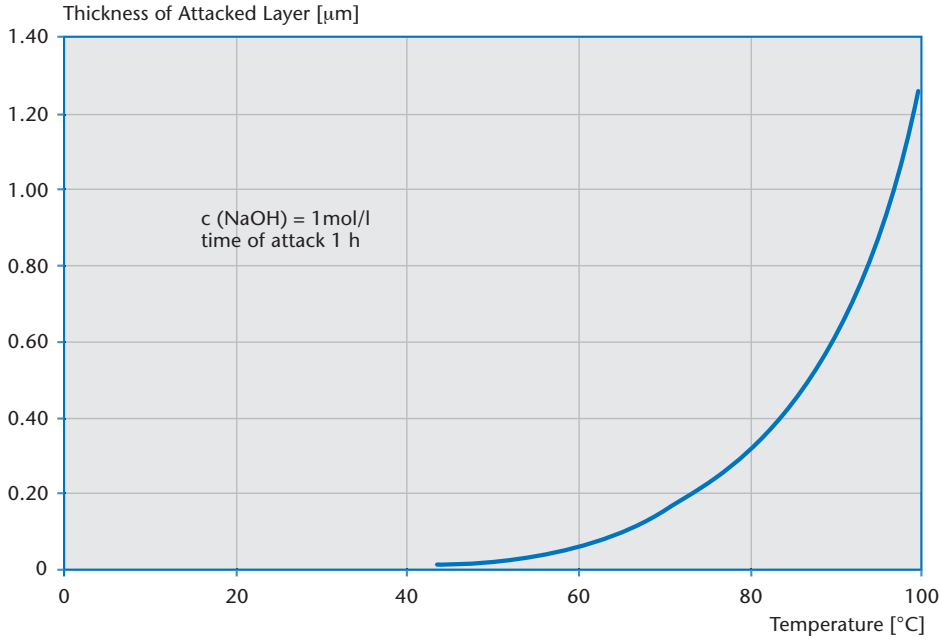
The phenomenon of tin traces on the surface is commonly known from the manufacture of soda-lime float glass. It is caused by an evaporation effect in the float bath atmosphere. These values are considerably lower for BOROFLOAT® 33 than for soda-lime float glass on both the side in contact with the tin and on the other side which is exposed to the atmosphere. The reciprocal effect with coating is thus markedly less. It is recommended that the top side (labeled by the manufacturer) is used for coatings.

# Chemical Properties

▶ ***Attack of Acid on BOROFLOAT® 33 Surface – Related to Temperature, Calculated from Weight Loss***



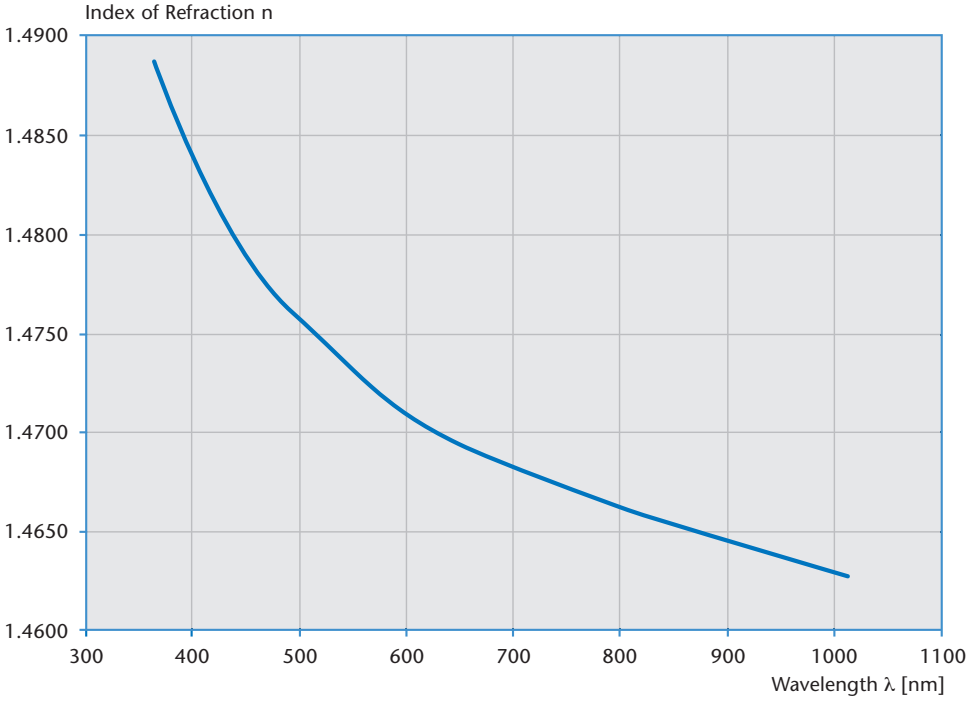

▶ ***Attack of Alkali on BOROFLOAT® 33 Surface – Related to Temperature, Calculated from Weight Loss***



# Optical Properties

| Wavelength λ (nm) | 435.8 | 479.9 | 546.1 | 589.3 | 643.8 | 656.3 |
|---|---|---|---|---|---|---|
| Index of Refraction n | 1.48015 | 1.47676 ($n_{F'}$) | 1.47311 ($n_e$) | 1.47133 | 1.46953 ($n_{C'}$) | 1.46916 |

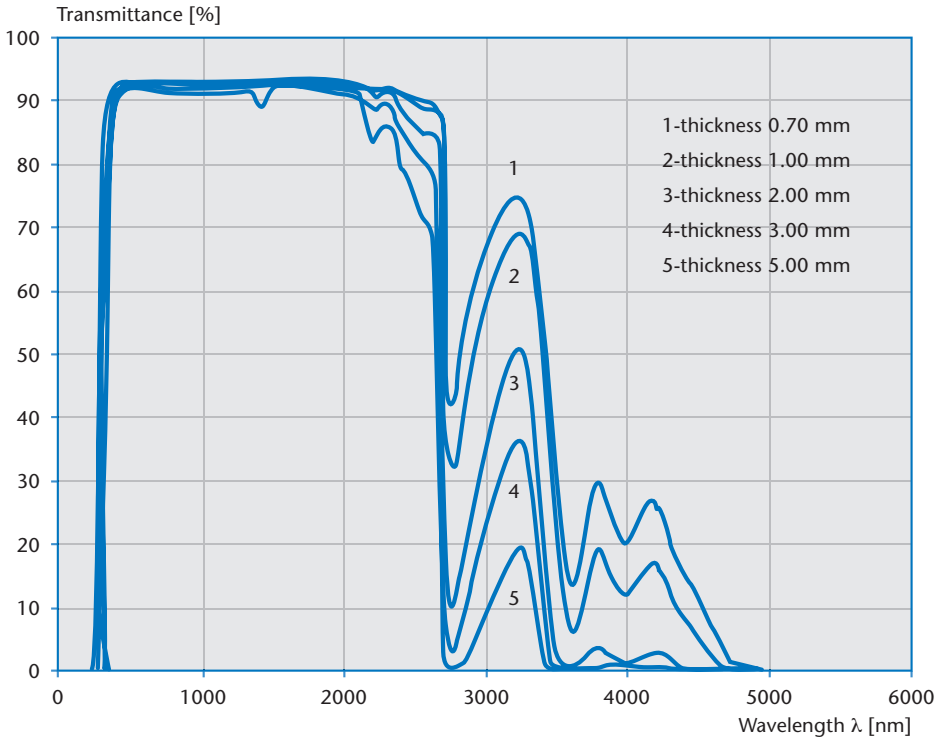
| Abbe Constant | $v_e = (n_e - 1) / (n_{F'} - n_{C'})$ | 65.41 |
|---|---|---|
| Refractive Index | $n_d$ ($\lambda_{587.6\ nm}$) | 1.47140 |
| Dispersion | $n_F - n_C$ | $71.4 \times 10^{-4}$ |
| Stress-optical Coefficent | K | $4.0 \times 10^{-6}$ mm² N⁻¹ |



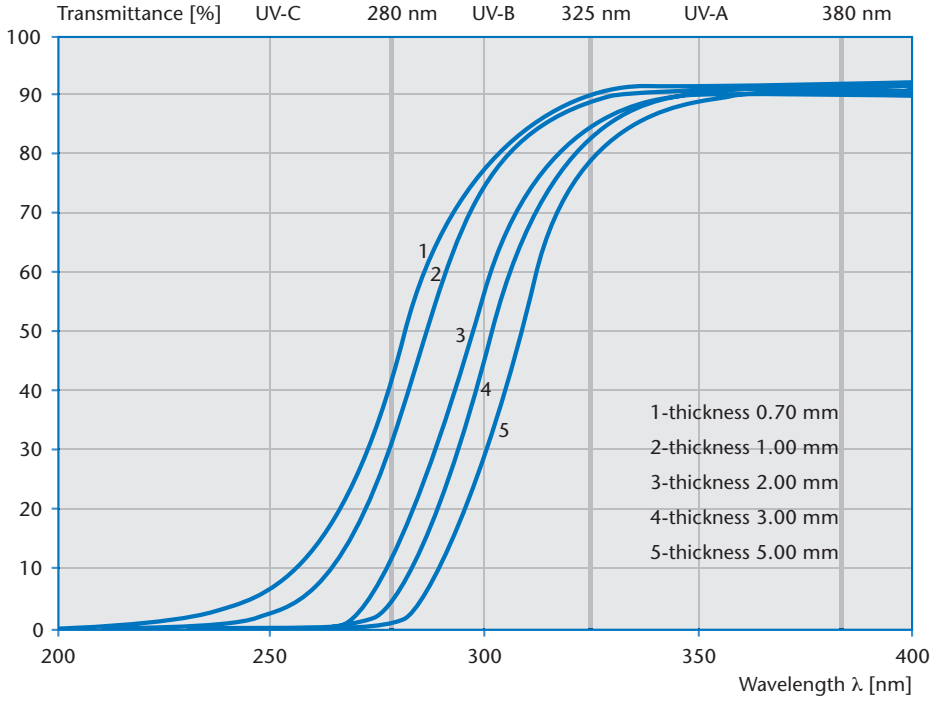

***Dispersion of BOROFLOAT® 33 – Index of Refraction (n) vs. Wavelength (λ)***

# Optical Properties

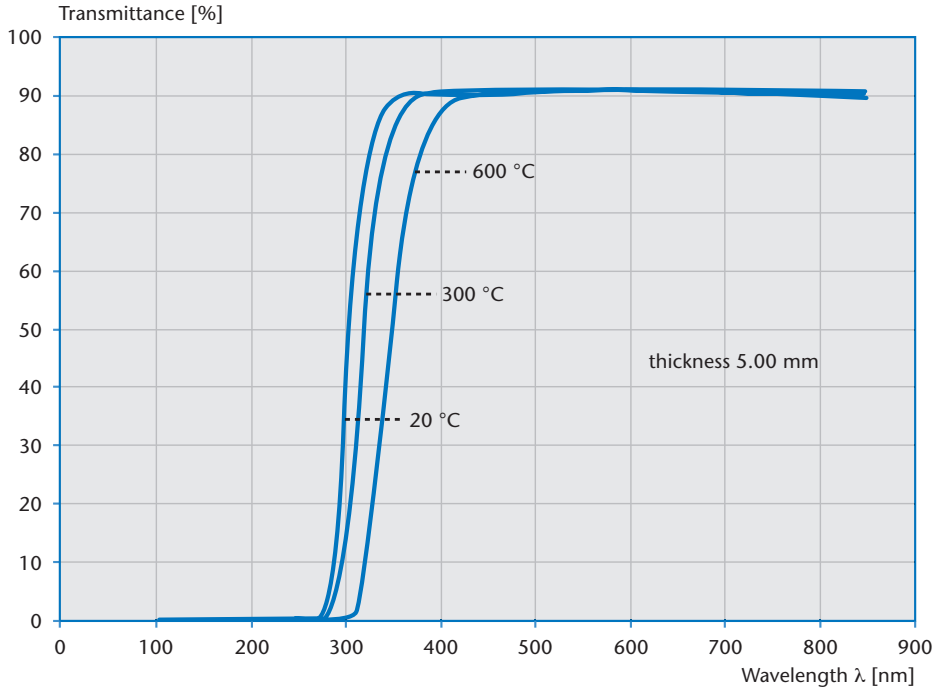
▶ ***BOROFLOAT® 33 –***
***Total Optical Transmittance***



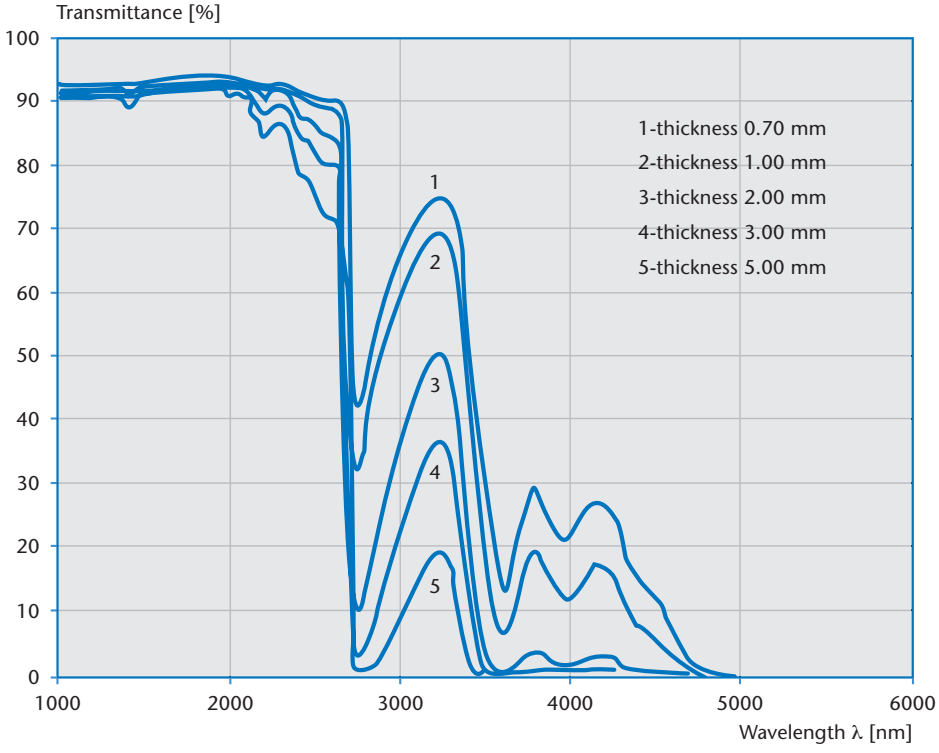

▶ ***BOROFLOAT® 33 –***
***Transmittance in the UV Range***



# Optical Properties



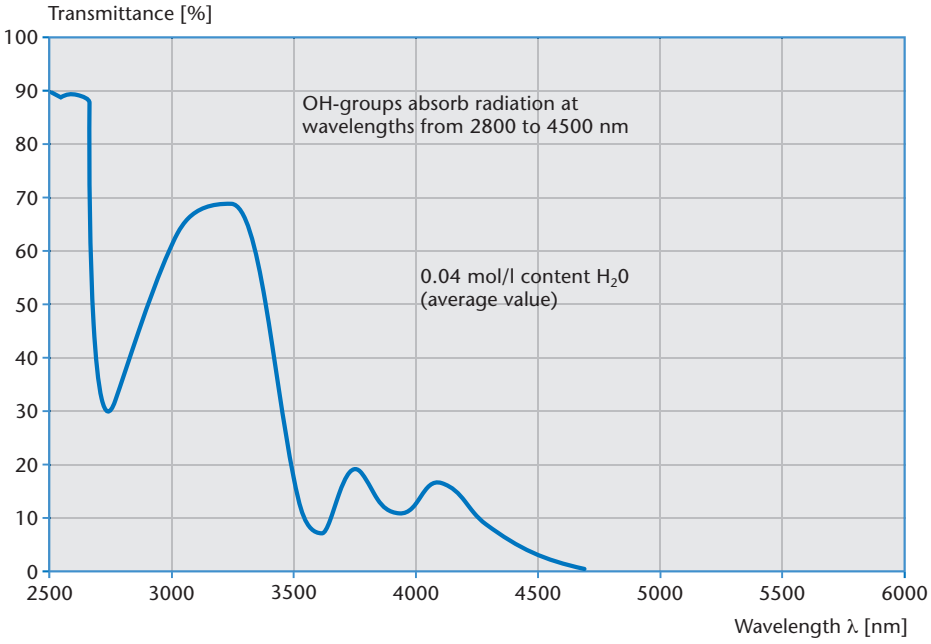

***BOROFLOAT® 33 –***
***Transmittance in the UV Range***
***Dependence on Temperature***



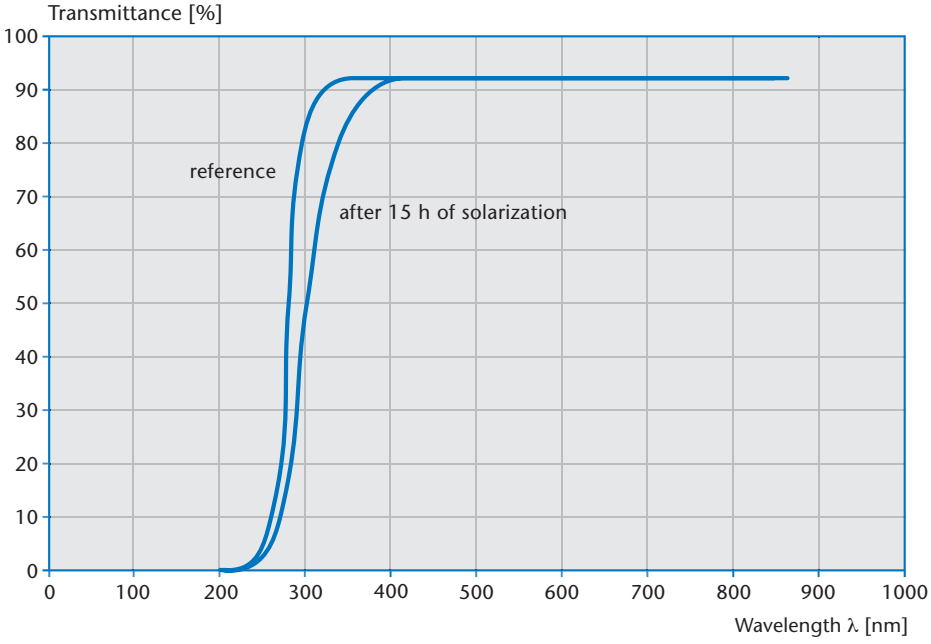

***BOROFLOAT® 33 –***
***Transmittance in the IR Range***

# Optical Properties

▶ ***BOROFLOAT® 33 – Influence of Water Content on the Transmittance***



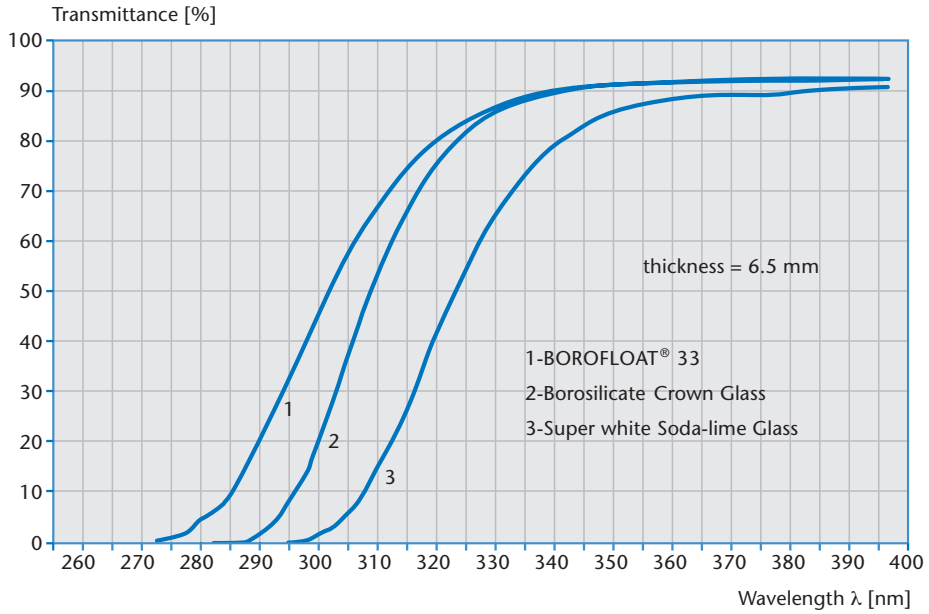

▶ ***BOROFLOAT® 33 – Resistance towards Radiation Degradation***



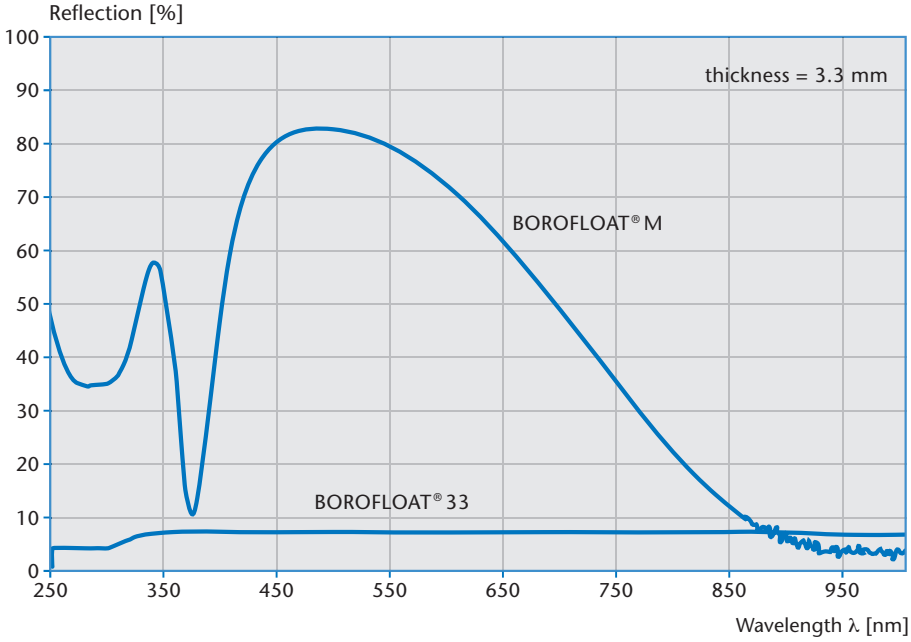

*The influence of radiation on the transmittance of BOROFLOAT® 33 is measured according to the SCHOTT test conditions:*

*The glass sample of a size 30 x 15 x 1 mm³ is radiation-exposed by using the high-pressure mercury vapor lamp HOK 4/120. This lamp works with a radiation intensity of 850 W/cm² and with a main wavelength of 365 nm.*

# Optical Properties



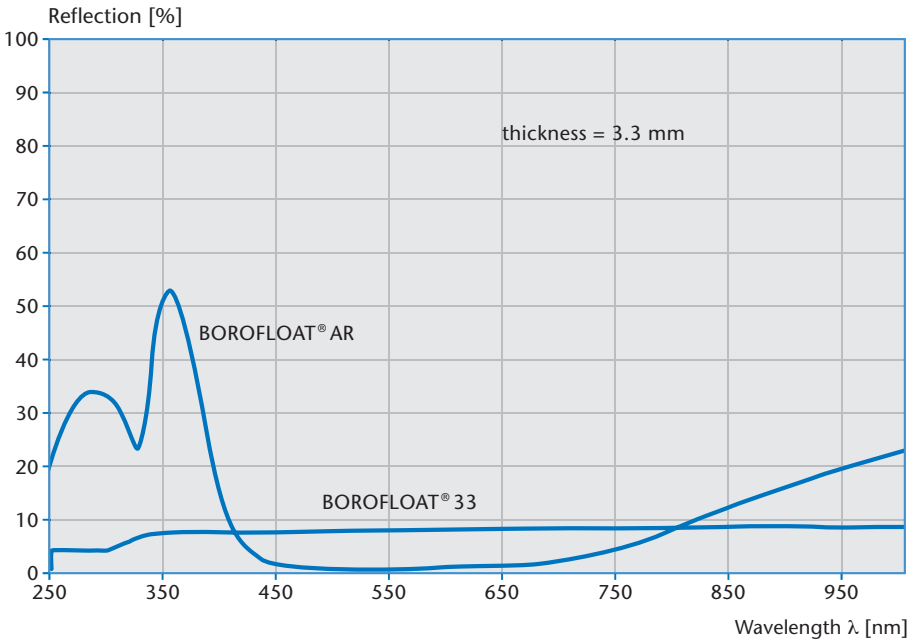

***Transmittance of BOROFLOAT® 33 in Comparison with Borosilicate Crown Glass and Soda-lime Glass (superwhite)***




***Reflection of BOROFLOAT® 33 in Comparison with BOROFLOAT® M (with reflective coating)***

# Optical Properties

▶ ***Reflection of BOROFLOAT® 33 in Comparison with BOROFLOAT® AR (with anti-reflective coating)***



# Optical Properties

Some materials have the ability to emit electromagnetic radiation after being activated by high frequency short-wave radiation of high energy intensity. This behavior of the materials is called fluorescence and it depends on the material's purity and structural characteristics, as well as the energy per pulse, pulse rate and excitation wavelength of the radiation.

BOROFLOAT® 33 is a material with high transmission showing very weak fluorescence intensities over the whole spectrum of light.

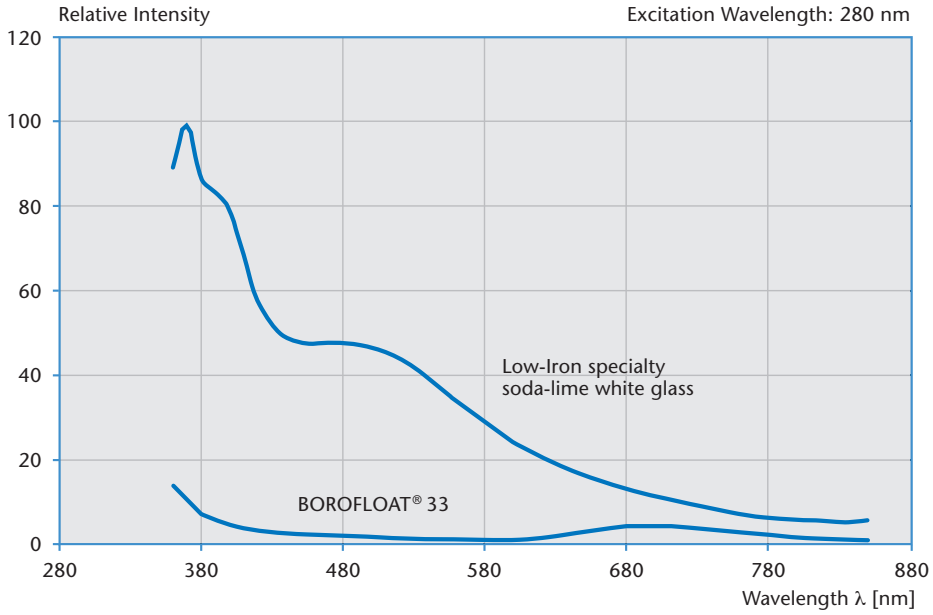
***Fluorescence Behavior of BOROFLOAT® 33***

| Wavelength (nm) | Lasing Medium | Wavelength (nm) | Lasing Medium | Wavelength (nm) | Lasing Medium |
|---|---|---|---|---|---|
| 308 | XeCl | 488 | Ar | 1047 | Nd:YLF |
| 325 | HeCd | 514.5 | Ar | 1053 | Nd:YLF |
| 337 | $N_2$ | 532 | Nd:YAG | 1064 | Nd:YAG |
| 350 | XeF | 632.8 | HeNe | 1153 | HeNe |
| 351.1 | Ar | 694.3 | Ruby | 1319 | Nd:YAG |
| 363.8 | Ar | 730-780 | Alexandrite | 1730 | Er:YLF |
| 427 | $N_2$ | 850 | Er:YLF | 2060 | Ho:YLF |
| 441.6 | HeCd | 905 | GaAs | 10640 | $CO_2$ |

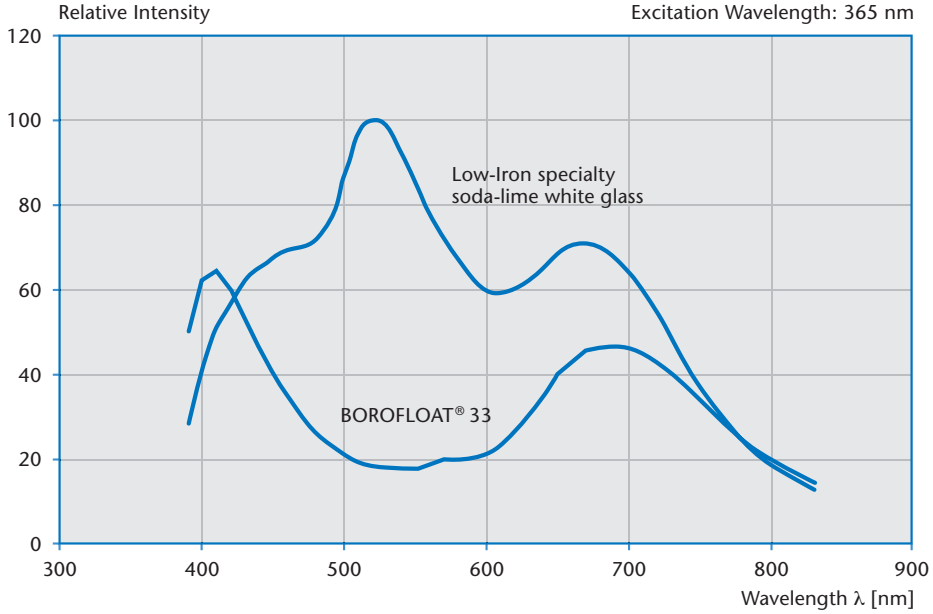
***Selected Standard Laser Wavelength and Lasing Media***

# Optical Properties

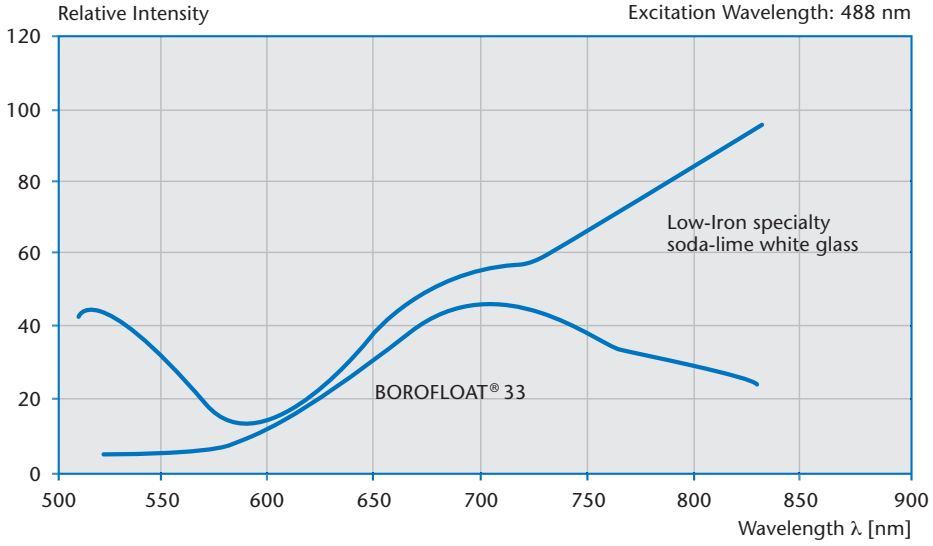
▶ ***Fluorescence Behavior of BOROFLOAT® 33 and Soda-Lime Glass Type for Different Wavelength Excitation***



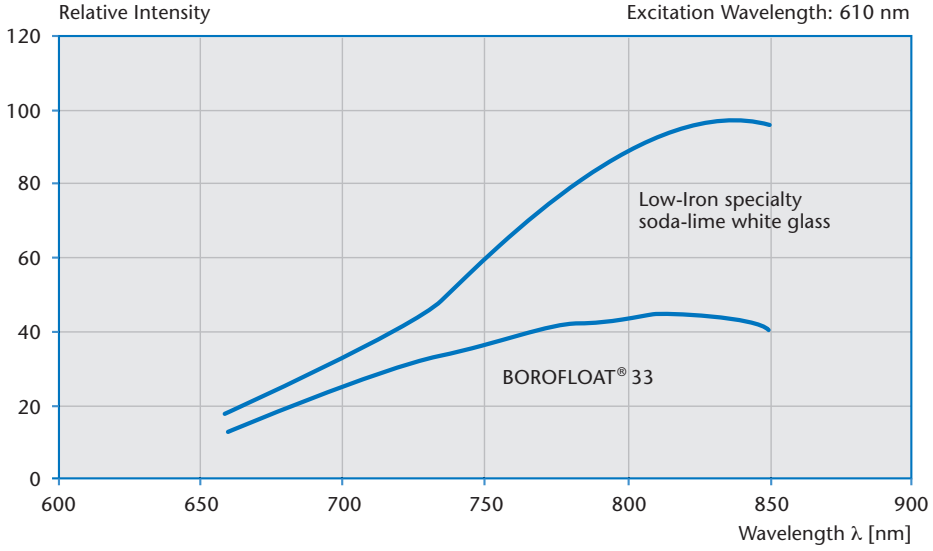

▶ ***Fluorescence Behavior of BOROFLOAT® 33 and Soda-Lime Glass Type for Different Wavelength Excitation***



# Optical Properties




***Fluorescence Behavior of BOROFLOAT® 33 and Soda-Lime Glass Type for Different Wavelength Excitation***

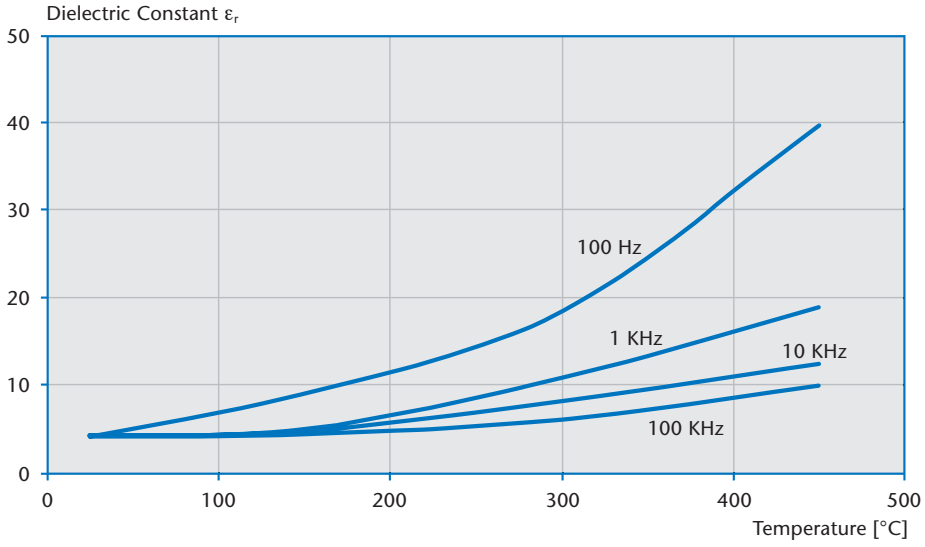



***Fluorescence Behavior of BOROFLOAT® 33 and Soda-Lime Glass Type for Different Wavelength Excitation***

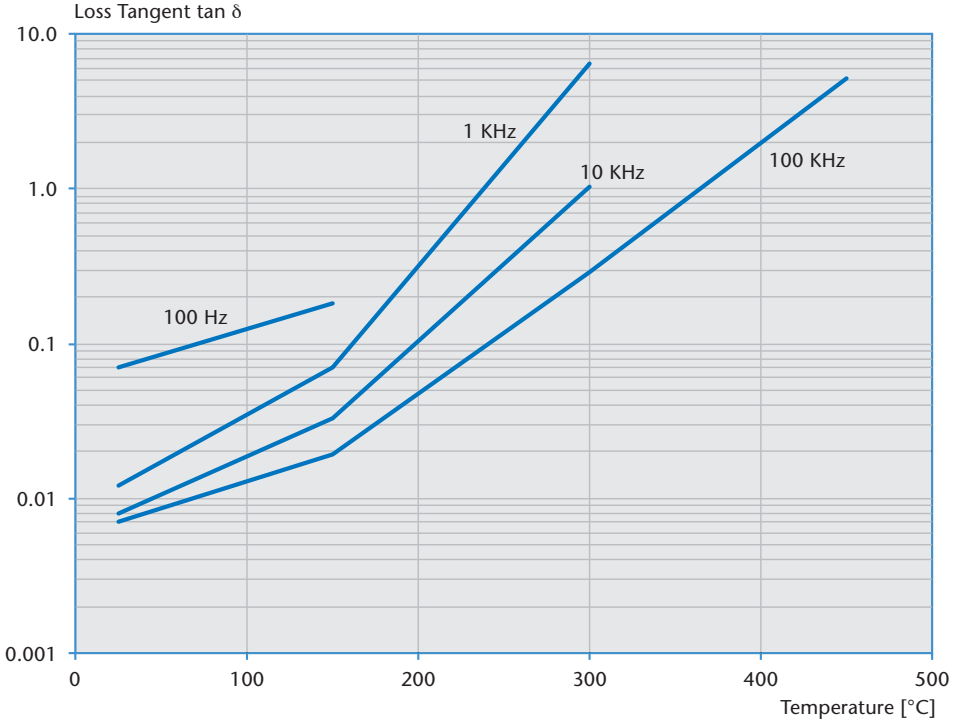
# Electrical Properties

| | | | |
|---|---|---|---|
| Dielectric Constant | $\varepsilon_r$ | (25 °C, 1 MHz) | 4.6 |
| Loss Tangent | tan δ | (25 °C, 1 MHz) | 37 x $10^{-4}$ |

▶ ***BOROFLOAT® 33 – Dielectric Constant as a Function of Temperature***

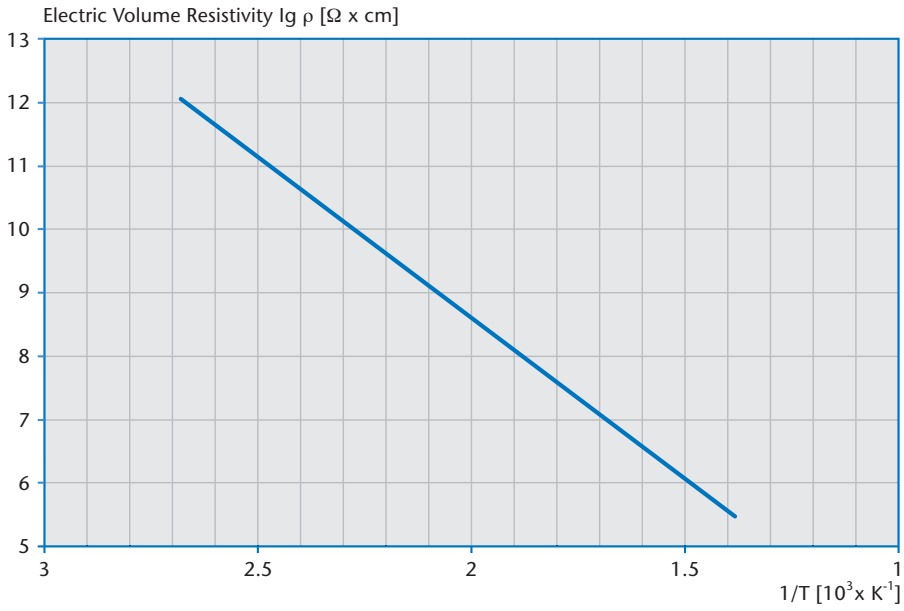



▶ ***BOROFLOAT® 33 – Loss Tangent as a Function of Temperature***

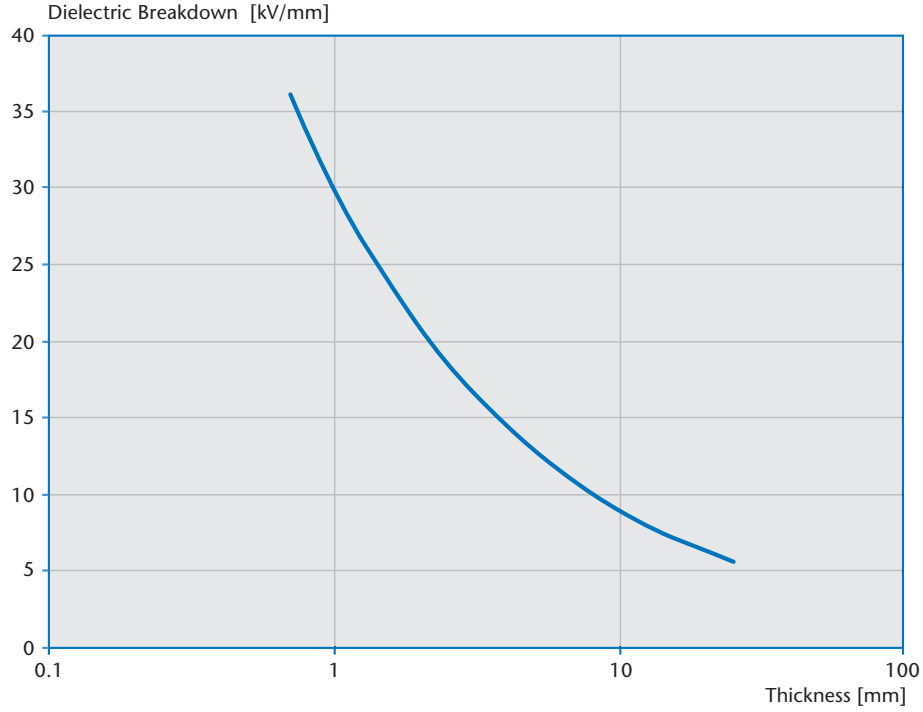


# Electrical Properties

| | | |
|---|---|---|
| Logarithm of the Electric Volume Resistivity: lg ρ | 250 °C | 8.0 Ω x cm |
| | 350 °C | 6.5 Ω x cm |




***BOROFLOAT® 33 –***
***Electric Volume Resistivity as a Function of Temperature***




***BOROFLOAT® 33 –***
***Dielectric Breakdown as a Function of Glass Thickness (in air)***

# Fitting

The basic guidelines for the fitting and handling of glass and glass-ceramics also apply to BOROFLOAT® 33.

1. When sizing frames and panels, the different thermal expansions of BOROFLOAT® 33 and the various frame materials plus any possible manufacturing tolerances must be taken into account.

2. If it is necessary for design considerations to use compression fixing of the glass in the frame, this pressure must be applied uniformly all around the edge of the panel (no uneven pressure).

3. The glass must be fitted in non-distorting frames. If it is not possible to avoid a small amount of torsion, a suitable permanently elastic gasket must be used to prevent the torsion in the frame being transferred to the glass.

4. There must be no direct contact between glass and metal (or any other hard element of construction). Permanently elastic, heat-resistant materials (e.g. mineral fiber materials) are recommended as an intermediate layer between glass and metal.

*Source: Zumtobel*

# Cleaning

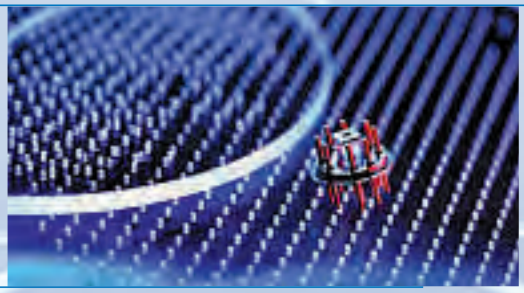
BOROFLOAT® 33 glass can be cleaned with any commercially available glass cleaner.

**Note:** Under no circumstances should abrasive sponges, scouring powders or other corrosive or abrasive cleaners be used, as these can cause damage to the surface of the glass.

*Source: Miele*

*BOROFLOAT® is a registered trademark of SCHOTT AG.*

# Additional Information



This presented material includes a variety of commonly referenced BOROFLOAT® 33 properties for commercial and industrial applications. As with all industrial products, the technical data can vary slightly. Therefore, all technical data presented in this brochure must be read as typical average values only.

This data is for reference information only and may vary for specific requirements. Secondary processing performed by others, who cut and finish the glass to enduser specifications, has a significant influence on the thermal shock resistance and mechanical properties that ultimately affect glass performance.

BOROFLOAT®´s application potential varies widely. Therefore, if you have any questions or concerns regarding the proper use of BOROFLOAT® 33 for a particular application, please contact SCHOTT.

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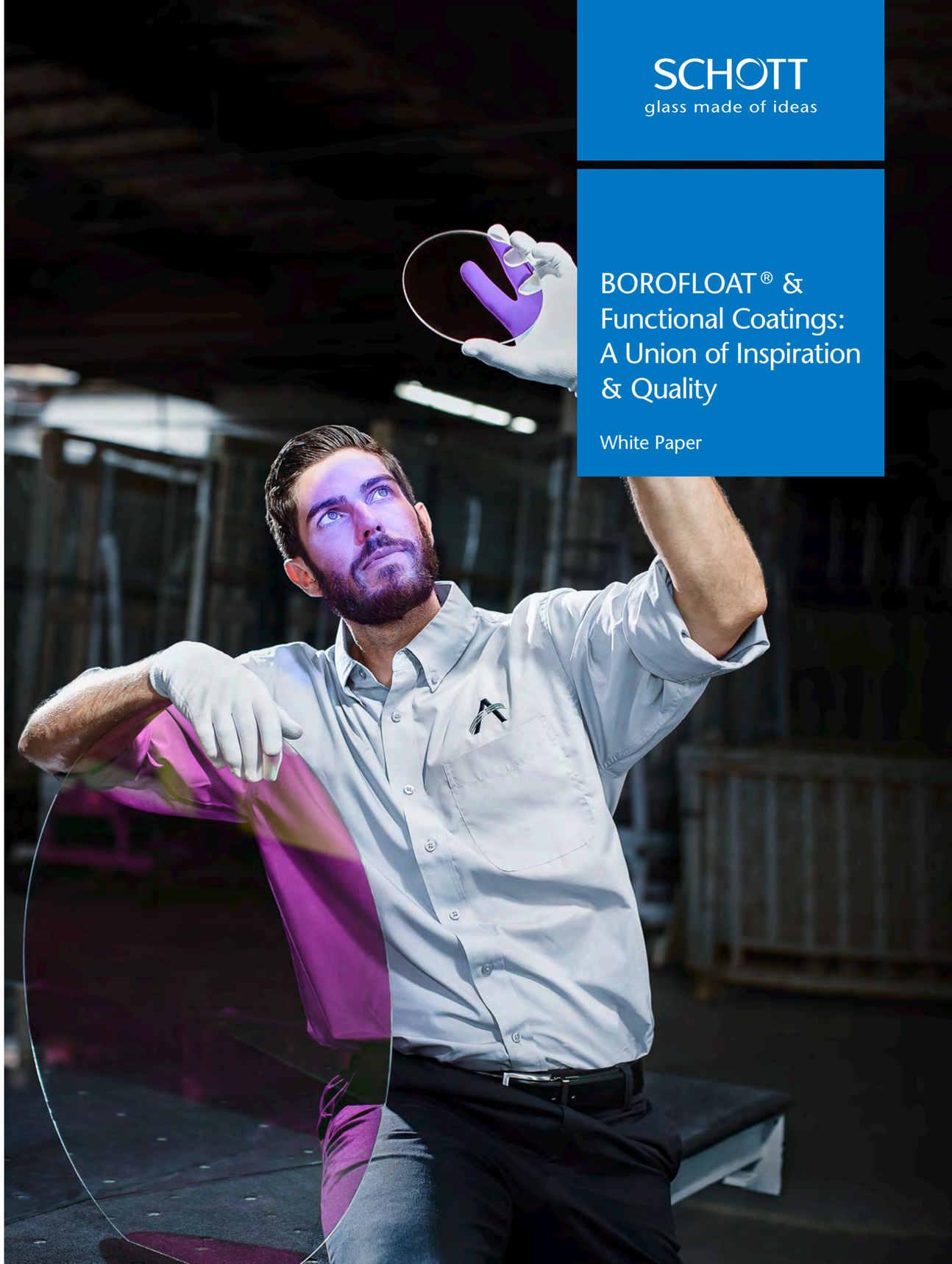
www.schott.com/borofloat/coatings

SCHOTT
glass made of ideas

# BOROFLOAT® & Functional Coatings: A Union of Inspiration & Quality

White Paper



# BOROFLOAT® & Functional Coatings: A Union of Inspiration & Quality

The performance requirements for optical filters and mirrors are highly dependent on the material's ability to reflect, absorb, enhance or modify incoming light. This can be accomplished with bulk optical glass materials or through coatings that are applied to a pristine glass substrate. Coatings usually allow significantly more freedom for customized light management design options which can be developed even further when a flat glass material with outstanding optical, thermal, mechanical and chemical properties is used. BOROFLOAT® borosilicate glass is such a unique substrate and has hence become the material of choice for robust high-temperature resistant dichroic filters, hot and cold mirrors.

## 1. Introduction

SCHOTT as a highly respected brand in the world of glass is especially well known for its advanced high-quality materials and components. Borosilicate glass was one of Otto Schott's greatest inventions as it stands up to high heat, resists chemical attack and has outstanding optical qualities. The glass, originally used as thermometer glass, labware and lamp cylinders, has evolved into a material with unlimited potential. Whether it be an oven door window, a biochip or a component used in theater spotlights, film projectors or diving robots, few glass types can claim to be as versatile as BOROFLOAT® – the world's first floated borosilicate glass available on the market in pristine quality for over 20 years.

Specialized coating companies have discovered BOROFLOAT® glass as a substrate for advanced coatings capable of performing under the most challenging conditions.

**BOROFLOAT® – The sum of its properties is what makes it unique for functional coatings**

- Exceptionally high transparency
- Outstanding thermal resistance
- Excellent mechanical strength
- Broad range of sizes and thicknesses

BOROFLOAT® glass is a top performer when it comes to conventional or specialized applications and is often the material of choice, even for price-sensitive projects.

## 2. BOROFLOAT® – the perfect choice for dichroic filters

The word dichroic derives from the Greek words "di" and "chroma" which stand for "two" and "color" and represents the amazing color-reflecting properties that dichroic materials are known for. Dichroic glass appears to have more than one color at the same time, especially when viewed at different angles and is reminiscent of the rainbow pattern seen when oil floats on water. The principle is similar as dichroic filters are created by coating glass with several ultra-thin layers (15 – 50) of metals or metal oxides that have different reflective indexes. Such layers are usually vacuum-deposited and less than 1 micrometer thin. The coating itself doesn't have its own inherent color, but rather bends light to reflect colors exactly as a prism or the oil film that creates a rainbow effect. The many combinations of coated layers allow for endless possibilities that inspire engineers and artists alike.

NASA originally developed dichroic glass in 1950's to protect sensitive spacecraft instruments from harmful cosmic radiation. However, the ability to reflect and absorb only certain wavelength ranges quickly opened new opportunities and today dichroic filters are used in architectural and entertainment lighting, fiber optic color wheels, light correction, electronic devices, heat and UV control applications, underwater lighting, medical photonics and many other optical applications.

Dichroic filters, also called inference filters, reflect unwanted light instead of absorbing the energy and are hence often used in high intensity light sources or light engines. Optical properties (perfect visible light transmittance)

along with the temperature resistance of the substrate determine the efficiency and maximum operation temperature of the filter product. Dyed plastics or commercial glass types have limited thermal resistance and plastic color gels tend to age and break down if exposed to high energy light sources. BOROFLOAT® glass however has excellent thermal resistance and low UV radiation damage (low susceptibility towards solarization), withstands thermal gradients and combines superior optical clarity with mirror-like surface quality. Due to its fully linked glass microstructure with a relatively low amount of non-bridging oxygen, BOROFLOAT® glass shows a low degradation behavior during high intensity radiation exposure.

It is therefore not surprising that it quickly became a substrate of choice for dichroic filters and color correction filters throughout the world. Dichroic filters made of BOROFLOAT® glass exhibit significantly better color filter characteristics (for instance steep UV cut-off performance, higher level of visible transmittance), higher laser and X-ray damage threshold and longer lifetimes than other flat glass substrates under challenging user conditions.

The thermal properties of BOROFLOAT® glass (uncoated substrate) are shown aside. Maximum thermal resistance of coated dichroic filters varies depending on the filter supplier but can reach up to 287 °C/550 °F.

### 2.1 Thermal properties

| Maximum operating temperatures | |
|---|---|
| Maximum Operating Temperature | |
| For short-term usage (< 10 h) | 500 ° C |
| For long-term usage (≥ 10 h) | 450 ° C |

Resistance to Thermal Gradients (RTG) and Resistance to Thermal Shock (RTS) must be considered when determining max. operation temperatures.

| Resistance to Thermal Gradients (RTG) | | | |
|---|---|---|---|
| Glass Thickness | Tempering | RTG | |
| | | $T_{change}$ * | $T_{heat-up}$ * |
| 3.8 mm | No | 123 K | 136 K |
| 6.5 mm | No | 119 K | 132 K |
| 11 mm | No | 52 K | 173 K |
| 18 mm | No | 31 K | 188 K |
| 6 mm | Thermal | > 300 K | |

Edges ground or polished

* $T_{change}$: sudden temperature change
$T_{heat-up}$: continuous heat-up

Panels measuring 25 x 25 cm² (10 x 10 inches²) are heated in the center of the panel to a defined temperature; the edges are maintained at room temperature. The temperature is increased within one minute to a level that initiates breakage of the test panel. The temperature is controlled via pyrometer. The RTG value is the difference in temperature between the hot center of the panel and the cool panel edge, at which breakage occurs in less than or equal to 5 % of the samples. In order to simulate damage that can occur in practical use, the samples are abraded with 220 grid sandpaper before testing.

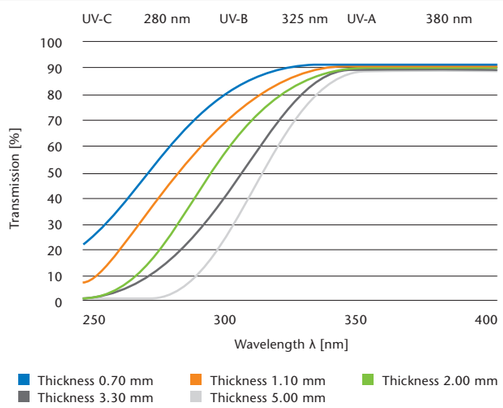
| Resistance to Thermal Shock (RTS) | |
|---|---|
| Glass Thickness | RTS (5 %-Fraktil) |
| ≤ 3.8 mm | 175 K |
| 5.0 – 5.5 mm | 160 K |
| 6.5 mm | 155 K |
| 11 mm | 142 K |
| 18 mm | 144 K |
| 25 mm | 128 K |

Panels measuring 20 x 20 cm² (8 x 8 inches) are heated in an oven with circulating air and afterwards doused in the center with 50 ml of cold water (68 degree F). The temperature is controlled via pyrometer. The RTS value is the difference in temperature between the hot panel and the cold water, at which breakage occurs in less than or equal to 5 % of the samples. In order to simulate damage that can occur in practical use, the samples are abraded with 220 grid sandpaper before testing.

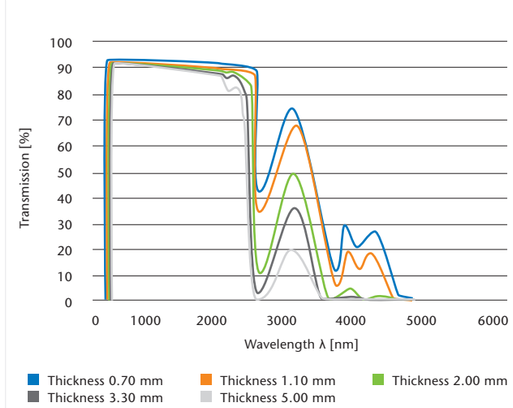
## 2.2 Optical Properties

The graph below shows the spectral transmittance range for selected BOROFLOAT® glass thicknesses and some basic optical characteristics. Additional information is available on request.

**Transmission in UV range**




**Transmission**




**Optical index of refraction**

| Wavelength λ (nm) | Refraction index n |
|---|---|
| 435.8 | 1.48015 |
| 479.9 | 1.47676 ($n_{F'}$) |
| 546.1 | 1.47311($n_e$) |
| 589.3 | 1.47133 |
| 643.8 | 1.46953 ($n_{C'}$) |
| 656.3 | 1.46916 |

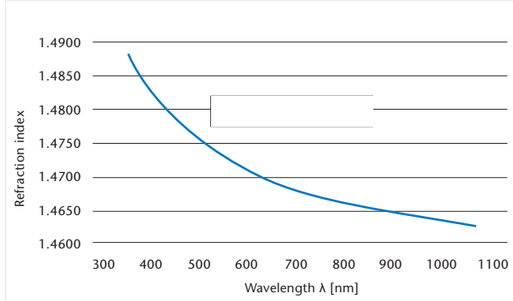
Mean reference values, not guaranteed values.

**Optical data**

| | |
|---|---|
| Abbe number ($v_e = (n_e - 1) / (n_{F'} - n_{C'})$) | 65.41 |
| Refraction index ($n_d$ ($\lambda_{587.6\ nm}$)) | 1.47140 |
| Dispersion ($n_F - n_C$) | 71.4 x $10^{-4}$ |
| Stress-optical coefficient (K) | 4.0 x $10^{-6}$ $mm^2$ $N^{-1}$ |

Average reference values, not guaranteed values.

**Dispersion**




Dichroic filters are also often referred to as beam splitters which are used to split light into two or more separate beams in optical systems. Beam splitters are essential for many applications such as interferometers, tele-prompters, vision systems, electronic displays, instrumentation, POP displays and flight simulators.



## 3. Hot & Cold Mirrors

Hot & Cold mirrors have the fascinating ability to either reflect infrared light (heat) and transmit visible light (hot mirrors) or – the opposite – transmit infrared light and reflect visible light (cold mirrors).

Both mirror types require substrates that have excellent clarity, high light transmittance and – given that operating temperatures are easily above 300 °C – are able to withstand high temperatures. BOROFLOAT® glass complies with such requirements and has been used as substrate material in many applications.

Similar to dichroic filters, vacuum deposited or sputtered multilayer coatings are applied to the substrate to create hot mirrors that either harness the reflected wavelengths or remove them from an application. This is especially important in optical systems where excessive heat can damage components or affect the characteristics of a light source. Hot mirrors are for instance used in halogen/HID lamps to increase filament temperatures resulting in less power consumption, increased efficiency, longer life-times and reduced cost. Typical hot mirrors reflect > 90 % of the IR wavelengths (750 nm – 1250 nm) while transmitting > 90 % of the visible light (425 nm – 675 nm), making them ideal as mirrors in LCD displays, (fiber optic) lighting, medical & dental applications, heat/light separation, aerospace, as IR filters in CCD cameras and cinemas, and as desktop projectors to prevent system damage. Various angles of incidence are available.

A cold mirror is a high efficiency heat/light separation device that is used to remove heat from light that hits a surface while still providing high levels of illumination. It transmits infrared light but reflects non-infrared light spectral bands, helping to eliminate heat that is unwanted or that can damage equipment. They are used as cool light sources in medical lighting (surgical and dental lights), dielectric mirrors in sensor technology, laser diodes, scanners and bar code readers, projectors and photocopiers.

## 4. Outlook

Dichroic filters and hot and cold mirrors are among many other optical applications for which BOROFLOAT® glass has been used. High transparency in the UV range down to 300 nm, greater than 92 % light transmittance capabilities in the Visible and Near IR wavelength range, outstanding colorless visual appearance, low auto-fluorescence and low solarization tendency are specific property requirements in many optical fields. A variety of optical glass materials comply with such requirements. However, the added thermal and chemical resistance, along with its high energy radiation exposure capabilities, make BOROFLOAT® glass an optical substrate unmatched in versatility and flexibility for many different applications that require more than just excellent optical characteristics.

The sum of its properties is what makes it unique!

SCHOTT
glass made of ideas

# Technical Glasses

## Physical and Technical Properties

SCHOTT is a leading international technology group in the areas of specialty glass and glass-ceramics. With more than 130 years of outstanding development, materials and technology expertise we offer a broad portfolio of high-quality products and intelligent solutions that contribute to our customers' success.

For over 130 years, SCHOTT has been shaping the future of glass technology. The Otto Schott Research Center in Mainz is one of the world's leading glass research institutions. With our development center in Duryea, Pennsylvania (USA), and technical support centers in Asia, North America and Europe, we are present in close proximity to our customers around the globe.

# Foreword

Apart from its application in optics, glass as a technical material has exerted a formative influence on the development of important technological fields such as chemistry, pharmaceutics, automotive, optics, optoelectronics and information technology. Traditional areas of technical application for glass, such as laboratory apparatuses, flat panel displays and light sources with their various requirements on chemical-physical properties, have led to the development of a great variety of special glass types. Through new fields of application, particularly in optoelectronics, this variety of glass types and their modes of application have been continually enhanced, and new forming processes have been developed. The hermetic encapsulation of electronic components has given decisive impetus to development activities. Finally, the manufacture of high-quality glass-ceramics from glass has opened entirely new dimensions, setting new standards for various technical applications.

To continuously optimize all commercial glasses and glass articles for existing applications and develop glasses and processes for new applications is the constant endeavor of SCHOTT. For such dynamic development, it is essential to be in close contact with the customers and to keep them as well informed as possible about glass.

SCHOTT Technical Glasses offers pertinent information in concise form. It contains general information for the determination and evaluation of important glass properties and also informs about specific chemical and physical characteristics and possible applications of the commercial technical glasses produced by SCHOTT. With this brochure, we hope to assist scientists, engineers, and designers in making the appropriate choice and make optimum use of SCHOTT products.

Users should keep in mind that the curves or sets of curves shown in the diagrams are not based on precision measurements but rather characterize and illustrate the typical property profiles of the respective glasses or glass types. Up-to-date characteristic values of particular glasses can be found in the tables of this brochure or in separate data sheets.

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# 1. Types of Technical Glasses

In the following, technical glasses are understood to be special glasses manufactured in the form of tubes, rods, hollow vessels and a variety of special shapes, as well as flat glass and glass powder for use mainly in chemistry, laboratory technology, pharmaceuticals, optoelectronics, and household appliance technology.

Glasses for purely optical applications are usually distinguished from these technical glasses by their special manufacturing processes and by their special compositional ranges.

For the purposes of classification, the multitude of technical glasses can be roughly arranged in the following six groups, according to their oxide composition (in weight percent). It should be noted, however, that certain glasses fall between these groups, and others completely outside of the groups, and therefore cannot be classified as belonging to these types.

## Borosilicate glasses

Characteristic of this type is the presence of substantial amounts of silica ($SiO_2$) and boric oxide ($B_2O_3 > 8\,\%$) as glass network formers.

The amount of boric oxide affects the glass properties in a particular way. Apart from the highly resistant varieties ($B_2O_3$ up to a maximum of 13 %), there are others that – due to the different way in which the boric oxide is incorporated into the structural network – have only low chemical resistance ($B_2O_3$ content over 15 %). Hence we differentiate between the following subtypes.

**Non-alkaline earth borosilicate glass (borosilicate glass 3.3)**
The $B_2O_3$ content for borosilicate glass is typically 12–13 % and the $SiO_2$ content over 80 %. High chemical durability and low thermal expansion ($3.3 \times 10^{-6}$/K) – the lowest of all commercial glasses for large-scale technical applications – make this a multitalented glass material.

High-grade SCHOTT borosilicate flat glasses are used in a wide variety of industries, mainly for technical applications that require either good thermal resistance, excellent chemical durability, or high light transmission in combination with a pristine surface quality.

Other typical applications for different forms of borosilicate glass include glass tubing, glass piping, glass containers, etc. especially for the chemical industry.

BOROFLOAT® 33, SUPREMAX® and DURAN® belong to this glass family.

**Alkaline earth containing borosilicate glasses**
In addition to about 75 % $SiO_2$ and 8–12 % $B_2O_3$, these glasses contain up to 5 % alkaline earths and alumina ($Al_2O_3$). To this subtype of slightly softer glasses (as compared with non-alkaline earth borosilicate glass), which have thermal expansion of between $4.0–5.0 \times 10^{-6}$/K, belong the chemically highly resistant varieties FIOLAX® 8412 and 8414 (“neutral glasses”), and SUPRAX® and 8488.

**High-borate borosilicate glasses**
Glasses containing 15–25 % $B_2O_3$, 65–70 % $SiO_2$, and smaller amounts of alkalis and $Al_2O_3$ as additional components, have low softening points and low thermal expansion. Sealability to metals in the expansion range of tungsten-molybdenum and high electrical insulation are their most important features. The increased $B_2O_3$ content reduces the chemical resistance; in this respect, high-borate borosilicate glasses differ widely from non-alkaline earth and alkaline earth borosilicate glasses.
Examples: 8245, 8250, 8337B, 8487.

## Aluminosilicate glasses

**Alkaline earth aluminosilicate glasses**
Characteristically, these glasses are free of alkali oxides and contain 15–25 % $Al_2O_3$, 52–60 % $SiO_2$, and about 15 % alkaline earths. Very high transformation temperatures and softening points are typical features. Main fields of application are glass bulbs for halogen lamps, high-temperature thermometers, thermally and electrically highly loadable film resistors and combustion tubes.
Examples: Halogen lamp glass types 8252 and 8253.

**Alkali aluminosilicate glasses**
The $Al_2O_3$ content of alkali aluminosilicate glasses is typically 10–25 % and the alkali content over 10 %. The high alkali content prepares the glass for ion exchange with bigger alkali ions in order to improve the surface compressive strength. High transformation temperatures and outstanding mechanical properties, e. g. hardness and scratch

behavior, are characteristic features of this glass type. Examples: Ion exchange glass types AS87 (8787) and LAS80 (8785).

## Aluminoborosilicate glasses

**Alkaline-free aluminoborosilicate glasses**
Typically, these glasses essentially consist of 55–65 % $SiO_2$, 15–20 % $Al_2O_3$, 5–10 % $B_2O_3$ and about 10 to 15 % alkaline earth oxides, without any additions of alkali oxides. A low coefficient of thermal expansion combined with high transformation temperature and good chemical stabilities makes them especially useful as substrate glasses for flat panel displays.
Examples: substrate glasses for TFT displays and AF32 (8266).

## Alkali-lead silicate glasses

Such glasses typically contain over 10 % lead oxide (PbO). Lead glasses containing 20–30 % PbO, 54–58 % $SiO_2$ and about 14 % alkalis are highly insulating and therefore of great importance in electrical engineering. They are used in lamp stems.

Lead oxide is also of great importance as an X-ray protective component in radiation shielding glasses.

## Alkali alkaline earth silicate glasses (soda-lime glasses)

This is the oldest glass type. It comprises flat glasses (window glass) and container glasses, which are produced in large batches. Such glasses contain about 15 % alkali (usually $Na_2O$), 13–16 % alkaline earths (CaO + MgO), 0–2 % $Al_2O_3$ and about 71 % $SiO_2$.

Different versions of the basic composition can also contain significant amounts of BaO with reduced alkali and alkaline earth content. Example: 8350.

Also belonging to this group are glasses with higher BaO content for X-ray protection such as those used in technical applications requiring radiation shielding. On a broader plane, certain crystal glasses (drinking glasses) can also be included.

Ingredients for the production of special glasses

## LAS-glass-ceramics

Due to their outstanding properties, crystallizable glasses in the Lithium-Aluminium-Silicate (LAS) system have achieved high commercial significance. Key properties are very low, even zero thermal expansion, optical transparency and high chemical resistance. Characteristically, these glasses contain 3–6 % $Li_2O$, 18–25 % $Al_2O_3$, 58–75 % $SiO_2$ (crystal constituents), 2–6 % $TiO_2 + ZrO_2$ (nucleating agents) and about 2 % alkaline and alkaline earths to improve glass melting (residual glass formers). MgO, ZnO and $P_2O_5$ can also enter the crystalline phase to form solid solution crystals. Coloration of glass-ceramics (by adding coloring oxides like $V_2O_5$, $Fe_2O_3$, CoO, NiO, $MnO_2$) creates black CERAN® cooktop panels. Transparent glass-ceramics are used in ROBAX® fireplace windows, CERAN CLEARTRANS® cooktop panels with underside coating, PYRAN® Platinum fire resistant glazings, ZERODUR® precision articles and a broad range of special applications under the trade name NEXTREMA®, a glass-ceramic material platform.
Examples: CERAN HIGHTRANSeco®, ROBAX®

# 2. Chemical Stability/Resistance of Glasses

Characteristically, glass is highly resistant to water, salt solutions, acids, and organic substances. In this respect, it is superior to most metals and plastics. Glass is attacked to a significant degree – particularly at higher temperatures – only by hydrofluoric acid, strong alkaline solutions, and concentrated phosphoric acid.

Chemical reactions with glass surfaces, induced by exchange, erosion or adsorption processes, can cause most diversified effects ranging from virtually invisible surface modifications to opacity, staining, thin films with interference colors, crystallization, bubbles, rough or smooth ablation, to name but a few. These changes are often limited to the glass surface, but in extreme cases they can completely destroy or dissolve the glass. Glass composition, contact medium, and operating conditions will decide to what extent such chemical attacks are technically significant.

## 2.1 Chemical reaction mechanisms with water, acids, and alkaline solutions

Chemical stability is to be understood as the resistance of the glass surface to chemical attack by defined agents, whereby temperature, exposure time, and the condition of the glass surface play important roles.

Every chemical attack on glass involves water or its dissociation product, i.e. $H^+$ or $OH^-$ ions. For this reason, we differentiate between hydrolytic (water), acid and alkali resistance. By water or acid attacks, small amounts of (mostly mono- or divalent) cations are leached out. In resistant glasses, a very thin layer of silica-gel then forms on the surface, which normally inhibits further attack (Figure 1a, b). Hydrofluoric acid, alkaline solutions and in some cases phosphoric acid, however, gradually destroy the silica framework and thus ablate the glass surface in total (see Figure 1c). In contrast, water-free (i.e. organic) solutions do not react with glass.

Chemical reactions are often increased or decreased by the presence of other components. Alkali attack on glass is thus hindered by certain ions, particularly those of aluminum. On the other hand, complex-forming compounds such as EDTA, tartaric acid, citric acid, and others increase solubility. In general terms, the glass surface reacts with solutions which induce small-scale exchange reactions and/or adsorptions. Such phenomena are observed, for example, in high-vacuum technology when residual gases are removed, or in certain inorganic chemical operations when small amounts of adsorbed chromium, resulting from treatment with chromic acid, are removed.

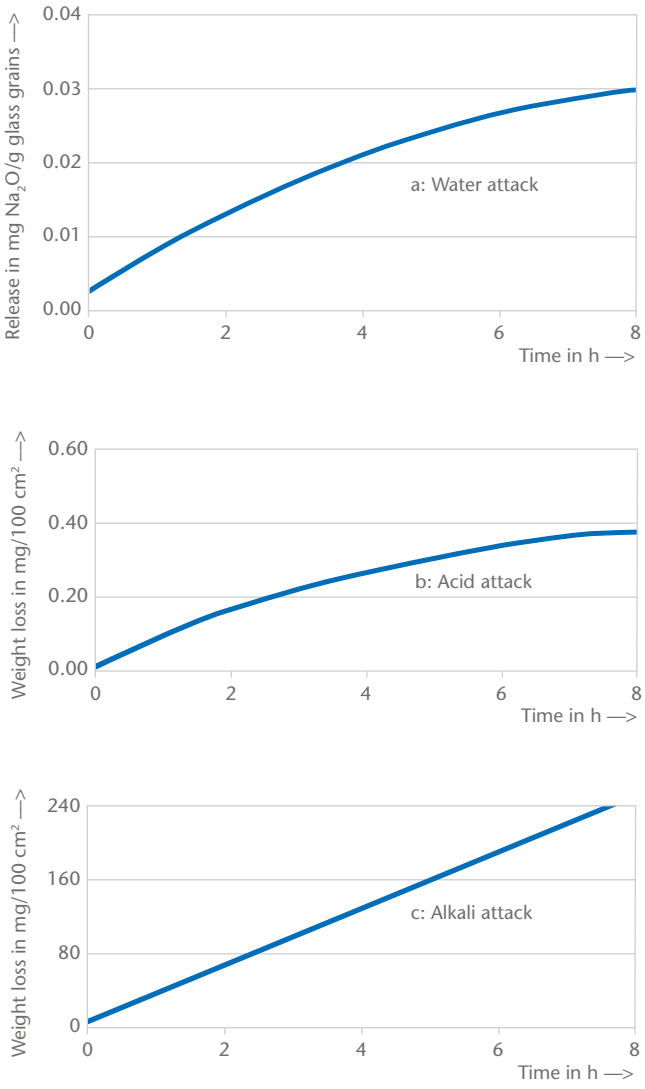



**Fig. 1.** Attack by water, acids and alkaline solutions on chemically resistant glass as a function of time

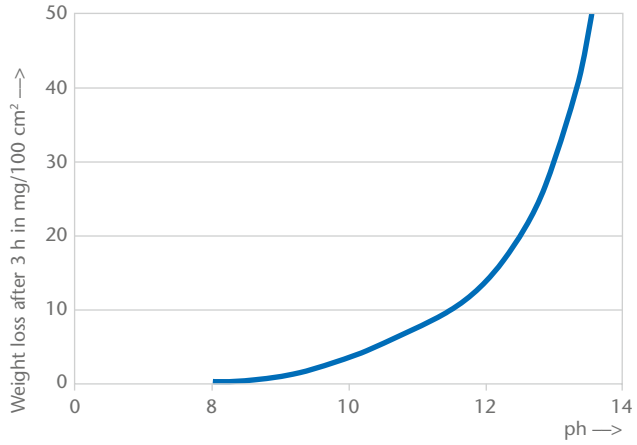



**Fig. 2.** Alkali attack on DURAN®/BOROFLOAT® 33/SUPREMAX® related to pH value at 100 °C

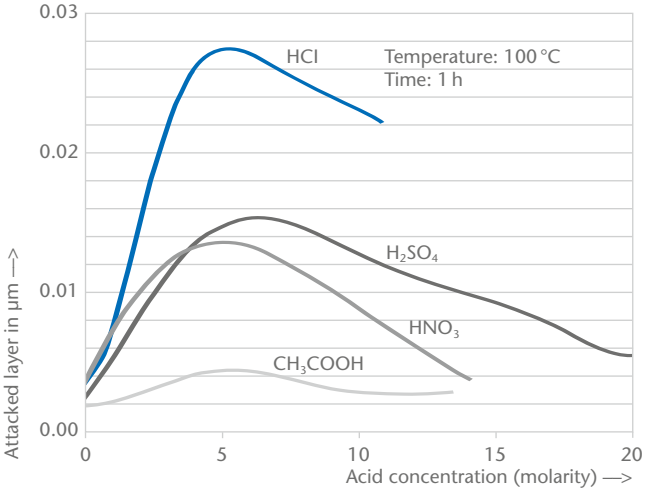



**Fig. 3.** Acid attack on DURAN®/BOROFLOAT® 33/SUPREMAX® as a function of concentration

Because acid and alkali attacks on glass are fundamentally different, silica-gel layers produced by acid attack obviously are not necessarily effective against alkali solutions and may be destroyed. Conversely, the presence of ions that inhibit an alkali attack does not necessarily represent protection against acids and water. The most severe chemical exposure is therefore the alternating treatment with acids and alkaline solutions. As in all chemical reactions, the intensity of interaction increases rapidly with increasing temperature (Figures 26 and 27).

In the case of truly ablative solutions such as hydrofluoric acid, alkaline solutions, or hot concentrated phosphoric acid, the rate of attack increases rapidly with increasing concentration (Figure 2). As can be seen in Figure 3, this is different for the other frequently applied acids.

## 2.2 Determination of chemical stability

In the course of time, many analysis methods have been suggested for determining the chemical stability of glass. In most cases, it is the glass surface that is analyzed either in its "as delivered" condition (with the original fire-polished surface) or as a basic material with its fire-polished surface removed by mechanical or chemical ablation, or after crushing.

The standardized DIN* test methods, which are universally and easily applicable, are the most reliable analysis methods. They include the determination of hydrolytic resistance (by two grain-titration methods and one surface method), of acid resistance to hydrochloric acid, and of alkali resistance to a mixture of alkaline solutions.

| Hydrolytic classes | Acid consumption of 0.01 mol/l hydrocholric acid per g glass grains ml/g | Base equivalent as $Na_2O$ per g glass grains µg/g | Possible designation |
|---|---|---|---|
| 1 | up to 0.10 | up to 31 | very highly resistant glass |
| 2 | above 0.10 up to 0.20 | above 31 up to 62 | highly resistant glass |
| 3 | above 0.20 up to 0.85 | above 62 up to 264 | medium resistant glass |
| 4 | above 0.85 up to 2.0 | above 264 up to 620 | low resistant glass |
| 5 | above 2.0 up to 3.5 | above 620 up to 1085 | very low resistant glass |

**Table 1.** Hydrolytic classes of DIN ISO 719

*Deutsches Institut für Normung e.V. German Institute for Standardization

### 2.2.1 Hydrolytic resistance (water resistance)

**Grain-titration method A**

(after leaching at 98 °C, according to DIN ISO 719; testing of glass as a material)

An amount of 2 g of powdered glass with 300–500 µm (ISO) grain size is heated with 50 ml water for one hour in a water bath at 98 °C. The extracted hydroxid ions, which are in the solution after ion exchange of protons against alkali ions, are titrated with hydrochloric acid, c(HCl) = 0.01 mol/l*, using methyl red sodium as an indicator. On the basis of the acid consumption (or its alkali equivalent), the glass is assigned to one of the five hydrolytic classes listed in Table 1. The hydrolytic classes shown in Table 20 (on page 72ff) were determined using the above method.

**Grain-titration method B**

(after leaching at 121 °C, according to DIN ISO 720; testing of glass as a material)

DURAN® borosilicate glass in the laboratory

In this method, which is particularly suitable for highly resistant glasses, 10 g of powdered glass (grain size 300–425 µm) is leached with 50 ml of water in an autoclave for 30 min at 121 °C. The extracted alkali is then titrated with hydrochloric acid, c(HCl) = 0.02 mol/l, using methyl red sodium as an indicator. Here, too, the acid consumption is a measure of the hydrolytic resistance. Presently, no allocation into classes exists for DIN ISO 720.

| Class[1] | Consumption of hydrochloric acid solution [c(HCl) = 0.02 mol/l] (4.2) per gram of glass grains ml/g | Equivalent of alkali expressed as mass of sodium oxide ($Na_2O$) per gram of glass grains µg/g |
|---|---|---|
| HGA 1 | up to and including 0.10 | up to and including 62 |
| HGA 2 | from 0.10 up to and including 0.85 | from 62 up to and including 527 |
| HGA 3 | from 0.85 up to and including 1.50 | from 527 up to and including 930 |

[1] "HGA" stands for the hydrolytic resistance of glass grains according to the autoclave test method.

**Table 2.** Limit values in the hydrolytic resistance grain test (autoclave test)

**Surface test method A**

(at 121 °C, according to ISO 4802-1 (2016) and current Ph. Eur. and USP)

Grain-titration methods are always carried out on crushed glass samples and the glass is tested as a material. With the surface test method, in contrast, the water resistance of the surface can be determined in its "as delivered" state. In this method, new, undamaged containers (e.g. flasks, test tubes, vials, ampoules) are filled with water and heated for 60 min at 121 °C in an autoclave. The leaching solution is then titrated with hydrochloric acid, c(HCl) = 0.01 mol/l, using methyl red sodium as an indicator. Distinguished according to volume, the containers are classified on the basis of the amount of acid required for neutralization.

The values gained by this method indicate not only the behavior of the glass material as such, but also reflect possible modifications induced in the glass surface during hot forming. Therefore, these values are not quoted in the tables included in this publication.

*The old term for concentration in "normal solutions N" has been replaced by "mol/l" in the SI system.

**Surface test method B**
(at 121 °C, according to ISO 4802-2 (2016) and current Ph. Eur.)
In this method, new, undamaged containers (e.g. flasks, test tubes, vials, ampoules) are filled with water and heated for 60 min at 121 °C in an autoclave. The leaching solution is then analyzed by using flame atomic emission or adsorption spectrometry (flame spectrometry). This is a direct and precise method for quantifying the specific leached ions in the solution. Distinguished according to volume, the containers are classified according to the mean value of the concentration of the oxides.

### 2.2.2 Acid resistance, according to DIN 12116

The glass surface to be tested is boiled for 6 h in 20 % hydrochloric acid [c(HCl) = 6 mol/l], and the loss in weight is determined in mg/100 cm². Using the half loss in weight, the glasses are then classified as follows:

| Acid class | Designation | Half loss in weight after 6 h mg/100 cm² |
|---|---|---|
| 1 | highly acid resistant | up to 0.7 |
| 2 | acid resistant | above 0.7 up to 1.5 |
| 3 | slight acid attack | above 1.5 up to 15 |
| 4 | high acid attack | above 15 |

**Table 3.** Acid classes

Acid classes for glasses manufactured by SCHOTT are listed in Table 20, p. 72ff.

### 2.2.3 Alkali resistance, according to DIN ISO 695

To determine the alkali resistance, glass surfaces are subjected to a 3 h treatment in boiling aqueous solution consisting of equal volumes of sodium hydroxide, c(NaOH) = 1 mol/l and sodium carbonate, c($Na^2CO^3$) = 0.5 mol/l. The loss in weight is then determined, and the glasses are classified as follows:

| Alkali class | Designation | Loss in weight after 3 h mg/100 cm² |
|---|---|---|
| 1 | low alkali attack | up to 75 |
| 2 | slight alkali attack | above 75 up to 175 |
| 3 | high alkali attack | above 175 |

**Table 4.** Alkali classes

Alkali classes for glasses manufactured by SCHOTT are listed in Table 20, p. 72ff.

The following borosilicate glasses have particularly high chemical resistance: DURAN®/BOROFLOAT® 33/ SUPREMAX® (8330), SUPRAX® (8488), FIOLAX® clear (8412), FIOLAX® amber (8414) and PYRAN® S (8341); see Table 6, p. 30.

FIOLAX® highly chemical resistant glass for save primary packaging in the pharmaceutical industry

## 2.3 The significance of chemical stability

### 2.3.1 Corrosion resistance in chemical plant applications

For such applications, the glasses must be resistant to the various chemical solutions to such a degree that manifold reactions can take place without running the risk of damaging the laboratory glass or the equipment by strong ablation. Moreover, no interfering amounts of glass components must be released into the reaction mixture. Attack by acids is of particular importance, both in laboratories and in chemical technology. Here, borosilicate glasses with their high acid resistance are superior to other materials. Up to the boiling point, their reactivity is very low; it then increases with increasing acid concentration, but decreases again at higher concentrations (Figure 3). The alkali attack, in contrast, increases exponentially with increasing alkali concentration (Figure 2).

A comparison of the effect of the alkaline mixture (concentration of alkaline components about 1 mol/l) with the effect of 6 mol/l hydrochloric acid (the most aggressive acid used in acid resistance tests) under standard conditions shows that the alkali attack increases by a factor of 1000 after extended exposure.

### 2.3.2 Release of glass constituents

In various processes of chemical technology, pharmaceuticals, and laboratory work, the material glass is expected to release no constituents (or a very minimum) into the reacting solutions or stored specimens.

Production of floated borosilicate glass

Because even highly resistant materials such as non-alkaline earth and alkaline earth borosilicate glasses react to a very small degree with the surrounding media, the fulfillment of this requirement is a question of quantity and detection limits. Concentrations of $10^{-6}$–$10^{-9}$ (i.e. trace amounts), which are measurable today with highly sophisticated analytical instruments, can be released even from borosilicate glasses in the form of $SiO_2$, $B_2O_3$, and $Na_2O$, depending on the conditions. However, solutions in contact with high-grade colorless DURAN® laboratory glass will not be contaminated by Fe, Cr, Mn, Zn, Pb, or other heavy-metal ions.

**2.3.3 Undesirable glass surface changes**

When an appreciable interaction between a glass surface and aqueous solutions occurs, there is an ion exchange in which the easily soluble glass components are replaced by $H^+$ or $OH^-$ ions. This depletion of certain glass components in the surface leads to a corresponding enrichment in silica, which is poorly soluble, and thus to the formation of a so-called silica-gel layer. This layer proves, in most cases, to be more resistant than the base glass. When its thickness exceeds about 0.1–0.2 µm, interference colors caused by the different refractive indices of layer and base glass make this silica-gel layer visible to the unaided eye. With increasing layer thickness, it becomes opaque and finally peels off, destroying the glass.

In the case of technical laboratory glass, the first stages are only a question of aesthetics. The functionality of the glass is not influenced in any way. In optical glasses, however, interference colors and opacity are usually unacceptable, and in glasses for electrical engineering, applicability may be reduced. In the final stage of degradation, when the silica-gel layer peels off, the glass of course becomes useless for any application.

Between these stages there is a wide scope of possible surface modifications, some of which, although optically visible, are of no practical significance, whereas others must be considered.

In the case of less resistant glasses, small amounts of water (air moisture and condensation) in the presence of other agents such as carbon dioxide or sulfur oxides can lead to surface damage. In the case of sensitive glasses, hand perspiration or impurities left by detergents can sometimes induce strongly adhering surface defects, mostly recognizable as stains. If the contaminated glass surfaces are reheated (> 350–400 °C), the contaminants or some of their components may burn in. Normal cleaning processes will then be ineffective and the whole surface layer will have to be removed (e.g. by etching).

**2.3.4 Desirable chemical reactions with the glass surface (etching)**

Very strong reactions between aqueous agents and glass can be used for fundamental cleaning of glass. The complete ablation of glass layers leads to the formation of a new surface.

Hydrofluoric acid reacts most strongly with glass. Because it forms poorly soluble fluorides with a great number of glass constituents, it is mostly only used in diluted form. The best etching effect is usually achieved when another acid (e.g., hydrochloric or nitric acid) is added. A mixture of seven parts by volume of water, two parts of concentrated hydrochloric acid (c = 38 %) and one part of hydrofluoric acid (c = 40 %) is recommended for a moderate surface ablation of highly resistant borosilicate glasses. When chemically less resistant glasses (e.g. 8245, 8250) are exposed for five minutes to a stirred solution at room temperature, surface layers with thicknesses of 1–10 µm are ablated, and a transparent, smooth, completely new surface is produced.

Glasses can also be ablated using alkaline solutions, but the alkaline etching process is much less effective.

# 3. Mechanical and Thermal Properties

## 3.1 Viscosity

Between melting temperature and room temperature, the viscosity of glasses increases by 15–20 orders of magnitude. Within this viscosity range, glasses are subject to three different thermodynamic states:

1. melting range – above liquidus temperature $T_s$;
2. range of the supercooled melt – between liquidus temperature $T_s$ and transformation temperature $T_g$;
3. frozen-in, quasi-solid melt ("glass range"), below transformation temperature $T_g$.

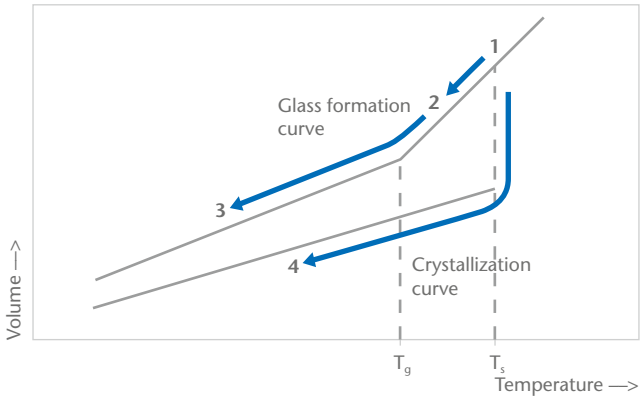



**Fig. 4.** Schematic volume-temperature curves for crystallization and glass formation:
1: liquid, 2: supercooled liquid, 3: glass, 4: crystal;
$T_s$: melting temperature, $T_g$: transformation temperature

The absence of any significant crystallization in the range of the supercooled melt (compare Figure 4 (2)) is of utmost importance for glass formation. Hence a basically steady and smooth change in the viscosity in all temperature regions is a fundamental characteristic of glass (Figure 5).

The temperature dependence of the viscosity (see Figure 6) is the crucial property for glass production.

Melting and fining (homogenization) must generally take place at viscosities ≤ 200 dPa·s; for glasses with low melting temperature, 1 dPa·s can be achieved.

Typical processing techniques for glasses, such as blowing, pressing, drawing and rolling, require viscosities in the range of $10^3$–$10^7$ dPa·s. As a characteristic temperature for this "working range," generally the temperature for $10^4$ dPa·s, called the **working point** (ISO 7884-1), is measured and quoted (Table 20, p. 72ff). Depending on the magnitude of the temperature interval between $10^3$ dPa·s and $10^7$ dPa·s, one distinguishes between "long" (large temperature difference, shallow slope) and "short" glasses.

At temperatures around the **softening point**, glass products deform rapidly under their own weight (forming by "sagging"), glass powders are sintered porously or densely, and glassblowing is carried out. The softening point is defined as the temperature at which the glass has a viscosity of $10^{7.6}$ dPa·s (method of measurement: ISO 7884-3).

Somewhat above $10^{10}$ dPa·s, the viscosity becomes increasingly time-dependent. With increasing viscosity (i.e. decreasing temperature), the delay in establishing structural equilibria finally becomes so large that under normal cooling conditions the glass structure at $10^{13}$ dPa·s can be described as solidified or "frozen-in." The low flow capability at this viscosity only suffices to compensate for internal stresses

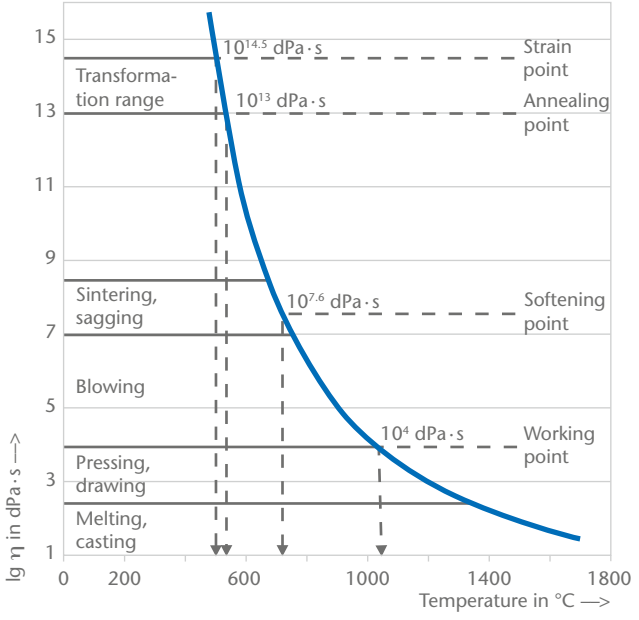



**Fig. 5.** Typical viscosity-temperature curve; viscosity ranges for important processing techniques and positions of fixed viscosity points

in the glass after 15 min of annealing time. On the other hand, the dimensional stability of the glass is sufficient for many purposes, and its brittleness (susceptibility to cracking) is almost fully developed. The glass is now in the transformation range, and many properties indicate this by changing the direction of their temperature dependence. Thus the change in the slope of the coefficient of linear expansion is used to define the transformation range by way of the so-called **transformation temperature** $T_g$ according to ISO 7884-8.

At this transformation temperature, most glasses show viscosities in the range of $10^{12}$–$10^{13.5}$ dPa·s. The "$10^{13}$ temperature," at which the glass has a viscosity of $10^{13}$ dPa·s (method of measurement: ISO 7884-4), is called the **annealing point**. It is of crucial importance for stress relaxation after the hot forming of glasses, indicating the upper temperature limit of the so-called annealing range, at which internal stress is released within minutes. The lower limit of the annealing range is expressed by the **strain point**, at which the glass has a viscosity of $10^{14.5}$ dPa·s (determination: extrapolation from the viscosity-temperature curve). For most glasses, the strain point lies about 30–40 K below the annealing point. Relaxation of internal stresses here already takes 3–5 hours. Therefore faster cooling is possible at temperatures below the strain point without freezing in new stresses. On the other hand, the strain point marks the maximum value for short-term heat load. Thermally prestressed glasses, in contrast, show significant stress relaxation already at 200–300 K below $T_g$. For glasses with precisely defined dimensions (e.g. etalons or gauge blocks) and in case of extreme demands on the stability of certain glass properties, application temperatures of 100–200 °C can already be the upper limit.

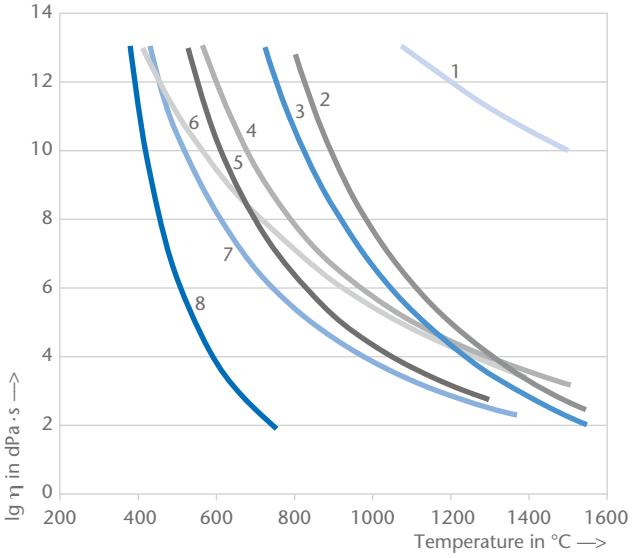



**Fig. 6.** Viscosity-temperature curves for some important technical glasses. 1: fused silica, 2: 8253, 3: 8252, 4: 8330, 5: 8350, 6: 8248, 7: 8095, 8: 8465. Glasses with steep gradients (8) are called "short" glasses and those with relatively shallow gradients (6) are "long" glasses

## 3.2 Strength

The high structural (= theoretical) strength of glasses and glass-ceramics (>$10^4$ MPa) cannot be used in practice since the strength of glass articles is actually determined by surface defects induced by wear. Contact with hard materials often causes damages in the surfaces of glass and glass-ceramic articles in the form of tiny chips and cracks, at whose tips critical stress concentrations may be induced by mechanical load, causing breakage of the articles.

In ductile materials such as metals, these stress concentrations are relieved by plastic flow. Glasses and glass-ceramics, in contrast, behave as brittle as ceramics. At typical application-specific temperatures and load times, they show no plastic flow by which the stress concentrations at the chip and crack tips could be relieved.

Regarding strength, surface damages are therefore particularly important for glass and glass-ceramic articles.

**Surface Condition**

As a result of wear-induced surface defects, glass and glass-ceramic articles have practical tensile strengths of 20–200 MPa, depending on the surface condition (Figure 7) and exposure conditions. Only a slight – as a rule negligible – dependence on the chemical composition is found for silicate glasses.

### Time and size dependence

For testing and applying tensile strength values, the time dependence of the load and the size of the surface area exposed to the stress are particulary important.

As a result of subcritical crack growth due to stress corrosion, a long lasting tensile stress may boost critical surface flaws, thus reducing the residual strength with time. Hence the strength of glass and glass-ceramics is time-dependent!

Stress corrosion causes the dependence of the measured fracture probability on the stress rate as depicted in Figure 8.

### Static fatique

Fracture analyses of broken specimens for the initial flaw, its origin and growth kinetics yield further information about the time dependence of the strength of glasses and glass-ceramics. Some rules are established for estimating the strength for a permanent load from fast tests with a constant load rate, see Figure 9 for example. As a simple rule, the permanent strength (for years of loading) will only amount to about 1/2 to 1/3 of the strength measured in fast experiments.

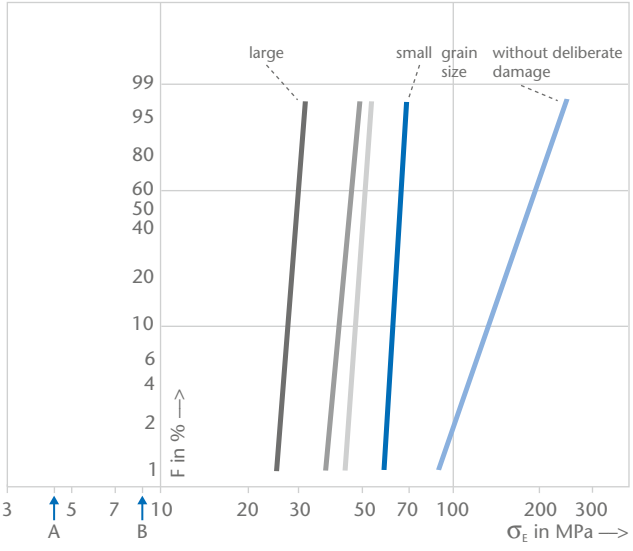
### Size dependence

Increasing the stressed area increases the probability of low strength flaws within this area. This relationship is important for converting of experimental strengths, which are mostly determined using small test specimens, to large glass articles such as pipelines, where many square meters of glass may be loaded (Figure 10).

### Strengthening

The defects that reduce the strength of the surfaces become ineffective if the glass surface ist subjected to compressive stress. The resulting strength of a glass article may be so high that it virtually sets no limits to technical applications. In glass articles with simple geometries, for example flat glass, the entire surface of the article can be put under compressive stress.

The toughening can be caused by rapid cooling (quenching) of the softened glass (Figure 11) or, in suitable glasses, by an ion exchange in an approximately 50–200 µm thick surface layer. In subsequent external loading (tensile or bending), the externally induced stress adds to the internal stress. Up to the value of the compressive surface stress,




A: nominal strength values for chem. techn. large-scale units
B: … and for normal glass constructions

**Fig. 7.** Failure probability F for samples abraded by various size grains; predamaged surface area: 100 mm², rate of stress increase $\dot{\sigma}$ = 10 MPa/s

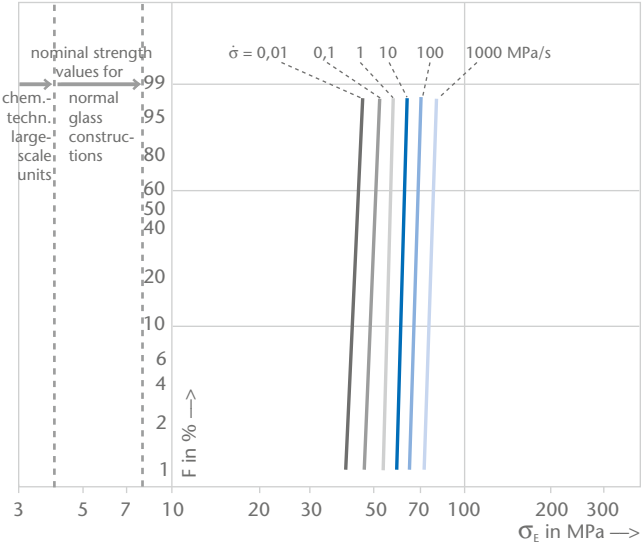



**Fig. 8.** Failure probability F of a predamaged surface for various rates of stress increase $\dot{\sigma}$. (predamaged area: 100 mm², grain size: 600)

a superimposed tensile stress keeps the surface under total compressive load. Thus, surface condition, loading rate, and loading time do not influence the strength.

## 3.3 Elasticity

The ideal brittleness of glasses and glass-ceramics is matched by an equally ideal elastic behavior up to the breaking point. The elastic moduli for most technical glasses is within the range of 50–90 GPa. The mean value of 70 GPa is about equal to Young's modulus of aluminum. Poisson's ratio of most glasses is in the range 0.21 to 0.25 and is lower than for metals or plastics.

## 3.4 Coefficient of linear thermal expansion

With few exceptions, the length and the volume of glasses increase with increasing temperature (positive coefficient).

The typical curve begins with a zero gradient at absolute zero (Figure 12) and increases slowly. At about room temperature (section A), the curve shows a distinct bend and then gradually increases up to the beginning of the experimentally detectable plastic behavior (section B = quasi-linear region). A distinct bend in the extension curve characterizes the transition from the predominantly elastic to the more visco elastic behavior of the glass (section C = transformation range). As a result of increasing structural mobility, the temperature dependencies of almost all glass properties are distinctly changed. This transformation range is characterized by the transformation temperature $T_g$ according to ISO 7884-8. Figure 13 shows the linear thermal expansion curves of five glasses; 8330 and 4210 roughly define the normal range of technical glasses, with expansion coefficients $\alpha_{(20°C;\ 300°C)} = 3.3–12 \times 10^{-6}/K$. The linear thermal expansion is an essential variable for the sealability of glasses with other materials and for thermally induced stress formation, and is therefore of prime importance for glass applications.

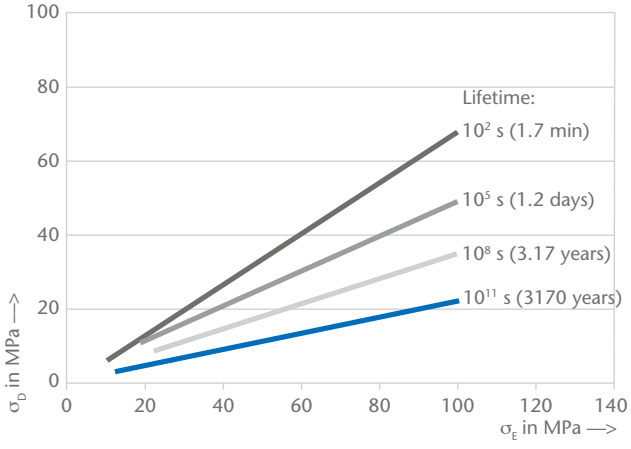



**Fig. 9.** Time-related strength $\sigma_D$ (strength under constant loading) compared to experimental strength $\dot{\sigma}_E$ at 10 MPa/s stress increase with lifetime $t_L$, in normally humid atmosphere (soda-lime glass).

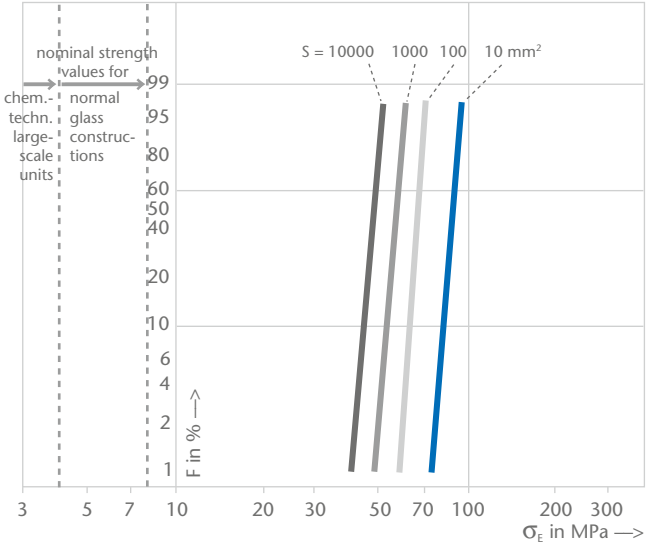



**Fig. 10.** Failure probability F for differently sized stressed areas S; all samples abraded with 600 mesh grit, stress rate $\dot{\sigma}$ = 10 MPa/s

**Sealability**

In fusion sealing with other materials, the decisive glass property is the linear contraction. As Figure 14 shows, the experimental setting point $T_E$ lies in the already sharply bent section of the glass curve, and the experimental setting temperature increases with increasing cooling rate. Predicting the linear contraction is only possible if the shape of the glass curve and the setting point $T_E$ for the respective cooling rate are known. The stress-optical measurement of stresses in test fusions with practice-oriented cooling rates (ISO 4790) is a simpler and much more accurate method of testing the sealability.

**Thermal stresses**

Owing to the low thermal conductivity of glass (typically 0.9–1.2 W/(m·K) at 90 °C, or a minimum of 0.6 W/(m·K) for high-lead-containing glasses), temperature changes produce relatively high temperature differences ΔT between the surface and the interior, which, depending on the elastic properties E (Young's modulus) and μ (Poisson's ratio), and on the coefficient of linear thermal expansion α, can result in stresses

$$\sigma = \frac{\Delta T\, \alpha\, E}{(1-\mu)}\ [\mathrm{MPa}].$$

In addition to the geometric factors (shape and wall thickness), the material properties α, E and μ decisively influence the thermal strength of glasses subjected to temperature variations and/or thermal shock. Thermal loads of similar articles made from different glasses are easily compared by means of the characteristic material value

$$\varphi = \frac{\sigma}{\Delta T} = \frac{\alpha\, E}{1-\mu}\ [\mathrm{MPaK^{-1}}],$$

which indicates the maximum thermally induced stress to be expected in a flex-resistant piece of glass for a local temperature difference of 1 K. Because cracking originates almost exclusively from the glass surface and is caused there by tensile stress alone, cooling processes are usually much more critical than the continuous rapid heating of glass articles.

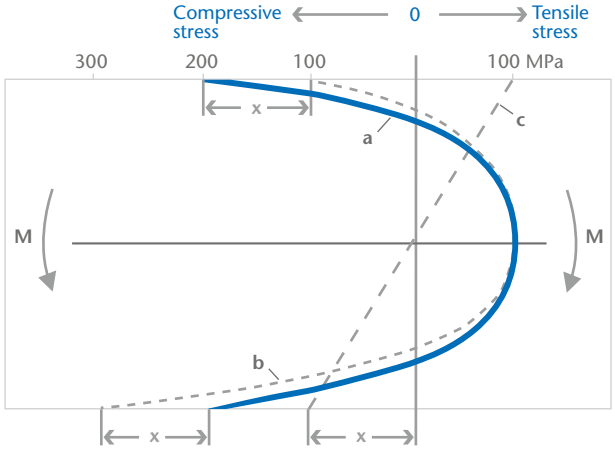



**Fig. 11.** Stress distribution across the thickness of thermally prestressed flat glass (a) without, (b) with additional bending M; (c) stress distribution in bending without prestressing

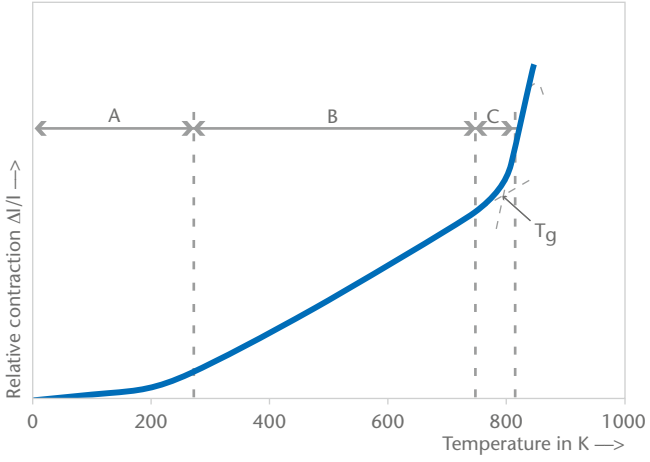



**Fig. 12.** Typical thermal expansion – temperature curve for glasses

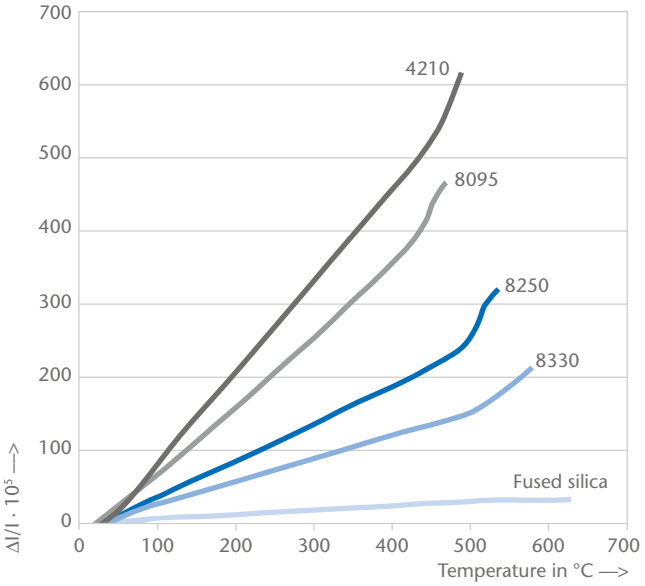



**Fig. 13.** Linear thermal expansion of various technical glasses and of fused silica

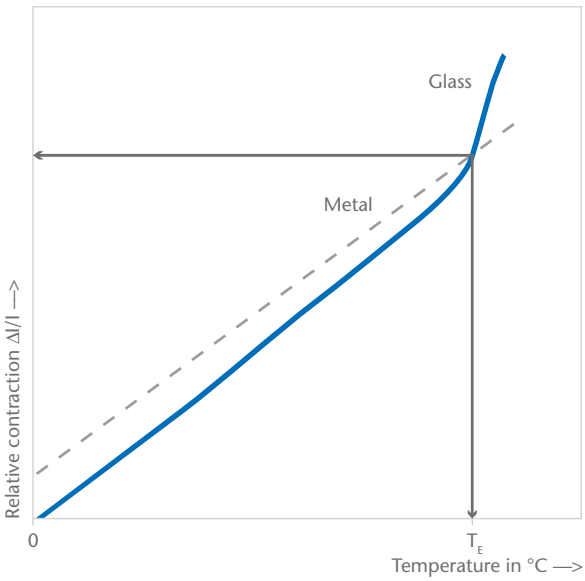



**Fig. 14.** Contraction/expansion curves of two fusion partners which are shifted so that they intersect at setting temperature $T_E$. The vertical difference thus describes the contraction difference with the correct sign.

PYRAN® Platinum fire-rated glass-ceramic resists fire without fracturing.

# 4. Electrical Properties

For more than 75 years, SCHOTT has been developing glass-sealed feedthroughs that enable electrical signals to pass through the walls of hermetically sealed packages, relays, for example.

As electrically highly insulating materials, glasses are used in electrical engineering and electronics for the production of high-vacuum tubes, lamps, electrode seals, hermetically encapsulated components, high-voltage insulators, etc. Moreover, glasses may be used as insulating substrates for electrically conducting surface layers (surface heating elements and data displays). Also in electronic packaging glasses are being widely used.

## 4.1 Volume resistivity

Electrical conductivity in technical silicate glasses is, in general, a result of the migration of ions – mostly alkali ions. At room temperature, the mobility of these ions is usually so small that the volume resistivities with values above $10^{15}$ Ω cm ($10^{13}$ Ω m) are beyond the range of measurement. The ion mobility increases with increasing temperature. Besides the number and nature of the charge carriers, structural effects of other components also influence the volume resistivity and its temperature relationship. An Arrhenius law which is in glass science sometimes also called Rasch-Hinrichsen law applies to this relationship at temperatures below the transformation range:

$$\lg \rho = A - B/T$$

$\rho$ = electrical volume resistivity
A, B = specific glass constants
T = absolute temperature

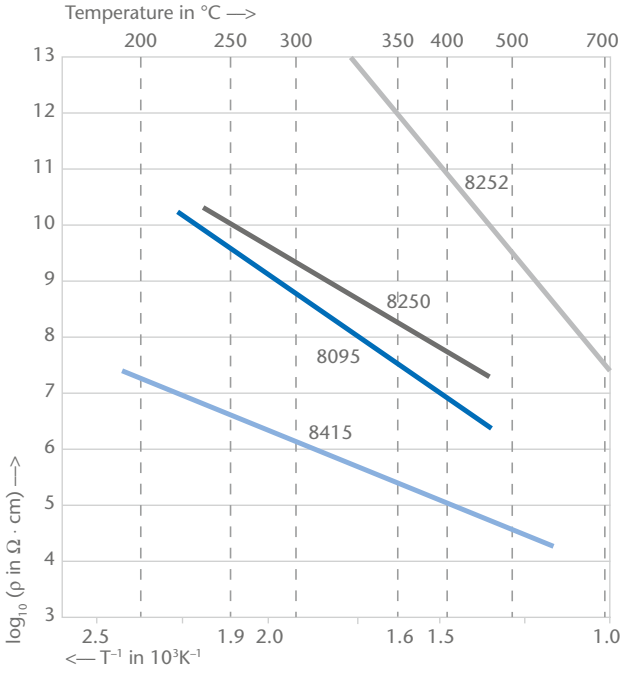



**Fig. 15.** Electrical volume resistivity of various technical glasses and fused silica related to the reciprocal of absolute temperature

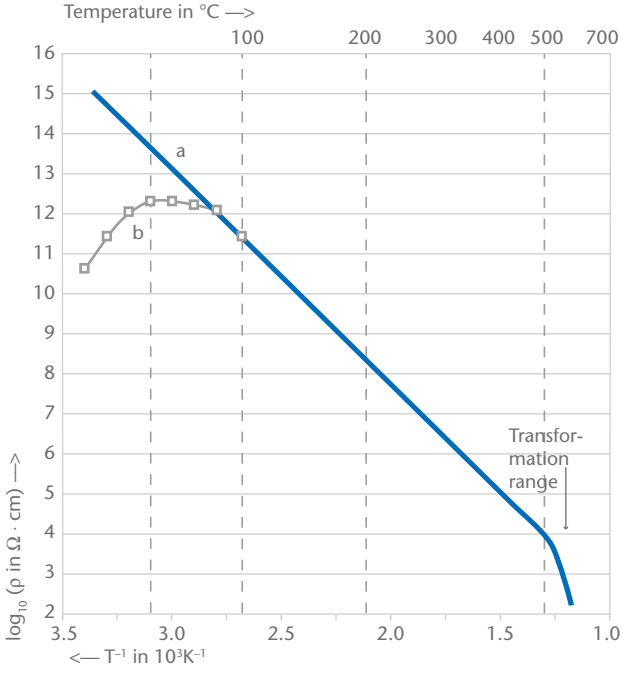



**Fig. 16.** Electrical resistance r of a soda-lime glass related to temperature (a) without, and (b) with a hydrated layer

The plot of lg ρ = f (1/T) thus yields straight lines (Figure 15). Because of the relatively small gradient differences for most glasses, the electrical insulation of glasses is often defined only by the temperature for $10^8$ Ω cm (= $10^6$ Ω m). According to DIN 52326, this temperature is denoted as $T_{k100}$. The international convention is to quote volume resistivities for 250 °C and 350 °C, from which the constants A and B and various other values below $T_g$ can be calculated.

## 4.2 Surface resistivity

The generally very high volume resistivities of glasses at room temperature are superposed in normal atmosphere by surface resistivities which are several orders of magnitude lower (Figure 16). The all-important factor is the adsorption of water on the glass surface. Depending on the glass composition, surface resistivities of $10^{13}$–$10^{15}$ Ω per square occur at low relative humidities, or $10^8$–$10^{10}$ Ω per square at high relative humidities. Above 100 °C, the effect of this hydrated layer disappears almost completely. Treatment with silicones also considerably reduces this effect.

Electrically conducting and transparent layers can be produced on glass by using semi-conducting oxides (e.g., of tin and indium). The surface resistance range is 1–100 Ω per square.

## 4.3 Dielectric properties

The dielectric constant $\varepsilon_r$ describes the relative increase in capacitance by introducing a polarizable dielectric into e.g a plate capacitor previously in vacuum.

Although $\varepsilon_r$ is not a constant but varies e.g. with material, frequency range and temperature, the term “dielectric constant” is misleading but still widely used instead of the correct term “relative permittivity.” In this brochure, we stay with the old term “dielectric constant.”

With dielectric constants generally between 4.5 and 8, technical glasses behave like other electrically insulating materials. The highest values are obtained for lead glasses such as 8531 ($\varepsilon_r$ = 9.5) and for ultra-high lead-containing solder glasses ($\varepsilon_r$ = ~20). Also lead free compositions with

dielectric constants in the range of $3.9 < \varepsilon < 21$ are available. The dependence of the dielectric constants $\varepsilon_r$ on frequency and temperature is relatively small (Figure 17). For a frequency range of $50 – 10^9$ Hz, $\varepsilon_r$ values will generally not vary by more than 10 %.

Reversing the polarity and shifting the dipoles of a dielectric situated in an alternating electrical field will cause heating and hence dissipation of energy as compared to ideal loss-free reactive power. The ratio of practical performance to ideal loss-free performance, which is dependent on the type of material as well as on frequency and temperature, is called the dielectric dissipation factor tanδ.

Due to the diverse mechanisms which cause such losses in glasses, there is a strong relationship with frequency, which shows minimum tanδ values in the region of $10^6 – 10^8$ Hz and increasing values for lower and higher frequencies (Figure 18).

At $10^6$ Hz, the dissipation factor tanδ for different glasses lies between $10^{-2} – 10^{-3}$; fused silica, with $10^{-5}$, has the lowest dissipation factor of all glasses. The special glass 8248 has relatively low losses and tanδ increases only slightly up to 5.5 GHz ($\tan\delta = 3 \times 10^{-3}$).

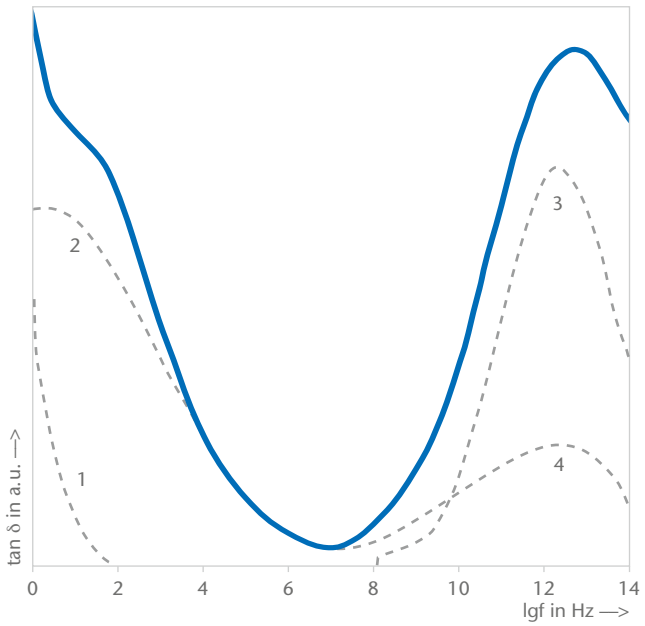



**Fig. 18.** Schematic representation of the frequency spectrum of dielectric losses in glass at room temperature (Stevels). The solid curve shows the total losses built-up from: 1. conduction losses, 2. relaxation losses, 3. vibration losses, and 4. deformation losses.

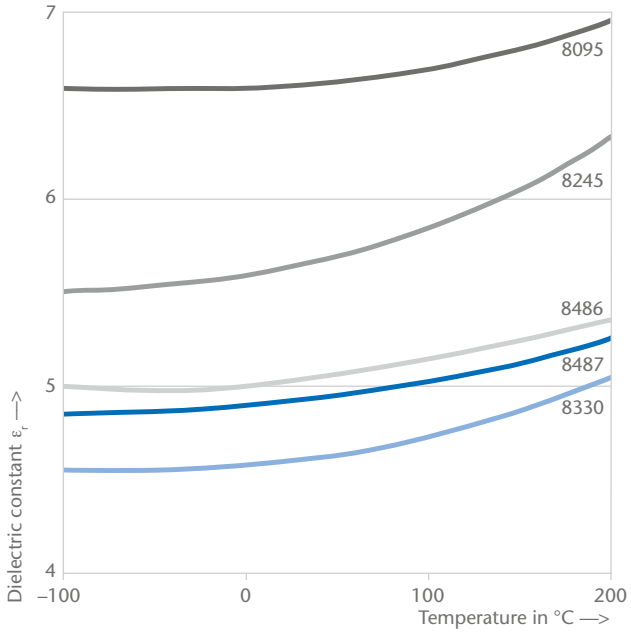



**Fig. 17.** Dielectric constant $\varepsilon_r$ of electro-technical glasses related to temperature, measured at 1 MHz

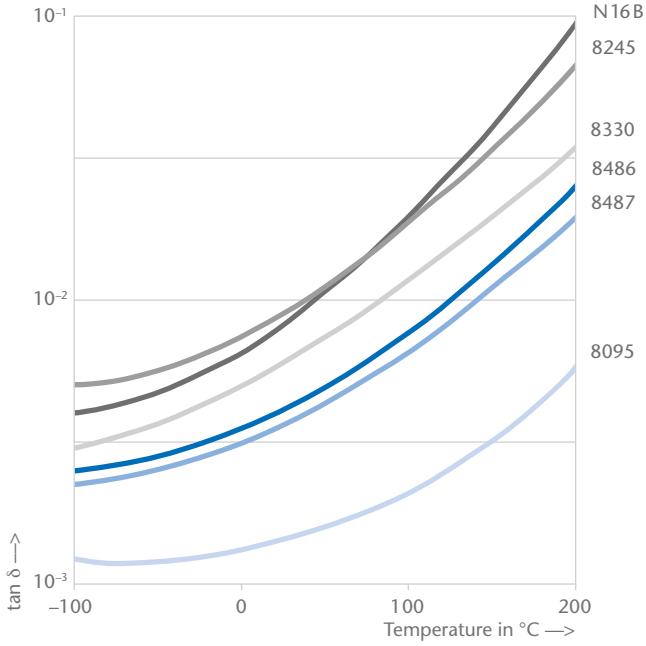



**Fig. 19.** Dissipation factor tanδ as a function of temperature in the range –100 to +200 °C, measured at 1 MHz

Several glasses, especially glasses with low or close to zero alkaline content are good dielectrics with low loss in the GHz range. Examples are AF32, BF33 (MEMpax), 8253. In Tab. 5, we show the dielectric loss of AF32 and MEMpax in the GHz range. In microwave electronics the loss if often characterized with the Q-factor Q = 1/tanδ or with Q*f (unit GHz) which is the product of the Q factor and the frequency.

The steep increase in dielectric losses with increasing temperature (Figure 19) can lead to instability, i.e. to overheating of the glass due to dielectric loss energy in the case of restricted heat dissipation and corresponding electrical power.

## 4.4 Dielectric strength

Glasses that are free of inhomogeneities such as bubbles and impurities are dielectrically very stable and often outperform porous electro-ceramics.

The dielectric strength of glasses depends on the frequency, the rate of increase in voltage, the temperature, the glass composition, and the external test conditions. Furthermore, the breakdown field strength increases substantially with decreasing glass thickness, indicating heat breakdown (interrelated increase in temperature and electrical conductivity) as the preferred breakdown mechanism. For ultra-thin glasses, the dielectric breakdown strength can show extremely large values. With an alkaline free glass, breakdown strength of 1200 kV/mm has been measured on 12 µm thick samples. In Figure 20 we schematically show the thickness dependence of the dielectric breakdown strength of AF32. "Cold" breakdown caused by the sudden formation of an electron avalanche is technically unimportant.

Approximate values for the dielectric strength of glass are field strengths of 20–40 kV/mm for glass thicknesses of 1 mm at 50 Hz at 20 °C, and 10–20 kV/mm for greater thicknesses. Decreasing values can be expected at higher temperatures and frequencies.

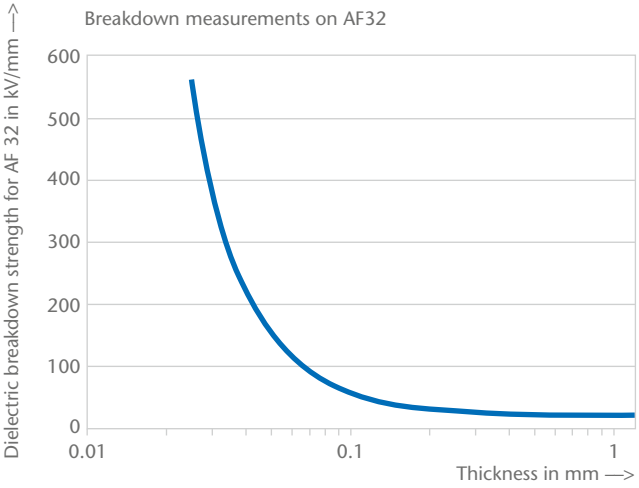



**Fig. 20.** Thickness dependence of the dielectric breakdown strength of AF32

**SCHOTT MEMpax®**

| Frequency in GHz[3)4)] | 1 | 2 | 5 | 24[7)] | 77[7)] |
|---|---|---|---|---|---|
| Dielectric constant (permittivity) $\varepsilon$,[2)] | 4.4 | 4.5 | 4.4 | 4.4 | 4.5 |
| Loss tangent *tan(δ)* in $10^{-4}$ | 58 | 62 | 73 | 130 | 140 |

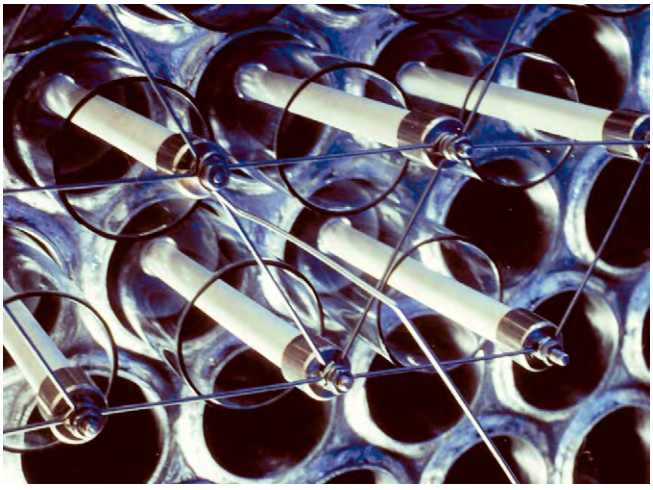
**SCHOTT AF 32® eco**

| Frequency in GHz[3)4)] | 1 | 2 | 5 | 24[7)] | 77[7)] |
|---|---|---|---|---|---|
| Dielectric constant (permittivity) $\varepsilon$,[2)] | 5.1 | 5.1 | 5.1 | 5.1 | 5.0 |
| Loss tangent *tan(δ)* in $10^{-4}$ | 35 | 39 | 49 | 90 | 110 |

[2)] The data of the dielectric constand $\varepsilon$, at 1 GHz, 2 GHz, 5 GHz, 24 GHz and 77 GHz have an accuracy of ± 0.1

[3)] The data at 1 GHz, 2 GHz, 5 GHz, are measured using a split-post-dielectric resonator and have an accuracy for the loss tangent of approx. $10^{-5}$

[4)] The data at 24 GHz and 77 GHz are obtained with an open resonator technique which has an accuracy for the loss tangent of approx. $10^{-3}$



Close-up of the front of an ozonizer, inside

# 5. Optical Properties

High homogeneity glass

## 5.1 Refraction of light

The ratio of the speed of light in vacuum to that in a defined material is called the refractive index $n_\lambda$ of that material. The refractive index of glass is dependent on the wavelength (dispersion). This is a decisive factor in purely optical applications.

The refractive indices $n_d$ of technical glasses are valid for $\lambda_d$ = 587.6 nm and generally lie within the range of 1.47 – 1.57. Exceptions to this rule are lead glasses with PbO contents of over 35 % (glass type 8531 : $n_d$ = 1.7). The principal dispersion $n_F - n_c$ ($\lambda_F$ = 486.1 nm, $\lambda_c$ = 656.3 nm) of technical glasses lies between 0.007 bis 0.013.

## 5.2 Reflection of light

At the boundary glass surface – air, the incident light is partly reflected. At perpendicular incidence, the reflectance R(λ) at wavelength λ is expressed as follows

$$R(\lambda) = \left(\frac{n(\lambda) - 1}{n(\lambda) + 1}\right)^2$$

For technical glasses R(λ = 587.6 nm) = $R_d$ lies within 3.6 % to 4.9 % per interface.

The transmittance $\tau_d$ and the reflectance $\rho_d$ of a non-absorbing plane-parallel glass plate with two glass-air surfaces, with multiple reflections taken into account, are expressed as follows

$$\tau_d = \frac{(1 - R_d)^2}{1 - R_d^2} = \frac{1 - R_d}{1 + R_d} = \frac{2n_d}{n_d^2 + 1}$$

and

$$\rho_d = \frac{2R_d}{1 + R_d} = \frac{(n_d - 1)^2}{n_d^2 + 1} \quad .$$

The transmittance $\tau_d$ at perpendicular incidence decreases correspondingly to values between 93.1 % and 90.6 %.

The reflection $r_d$ of a parallel glass plate can be reduced (and its total transmittance $\tau_d$ can be increased) by using so-called anti-reflective (AR) coatings. In its simplest form, a transparent layer on each surface with $n_{layer} = \sqrt{n_{glass}}$ and a thickness of $\lambda/4/n_{layer}$ will reduce the reflection for perpendicular incidence and wavelength $\lambda$ completely. For other wavelengths close to $\lambda$, the reflection is reduced but not canceled. With more complex multy-layer AR coatings, reflections in the visible range can be reduced to less than 1 % per surface.

## 5.3 Transmittance

Normally, glass is transparent to visible light and certain regions of UV and IR radiation. Losses in transmittance occur due to internal absorption and reflection, as indicated above. The so-called internal transmittance $\tau_i$ can be modified by using coloring agents (oxides of transition elements or colloids) or fine particles in the glass, which have different refractive indices (light scattering).

The internal transmittance $\tau_i$ of an absorbing glass is a function of the thickness d:
$\tau_i = e^{-\alpha d}$, where $\alpha$ is the spectral absorption coefficient.

The relation between spectral transmittance $\tau$ and spectral internal transmittance $\tau_i$ is:

$$\tau(\lambda) = \left(\frac{2n(\lambda)}{n(\lambda)^2 + 1}\right) \tau_i(\lambda)$$

The dependence of the factor $\left(\frac{2n(\lambda)}{n(\lambda)^2 + 1}\right)$

on wavelength is usually small, thus, a constant reflection factor P

$$P_d = \frac{2n_d}{n_d^2 + 1}$$

is sufficient for use in most cases.

The best UV transmission is achieved with pure fused silica (UV cut-off for 1 mm thickness is in the region of 160–180 nm); particularly good UV-transmitting multi-component glasses have cut-offs of up to 220 nm wavelength (Figure 21); normal technical glasses (Figure 22) already absorb considerably at 300 nm.

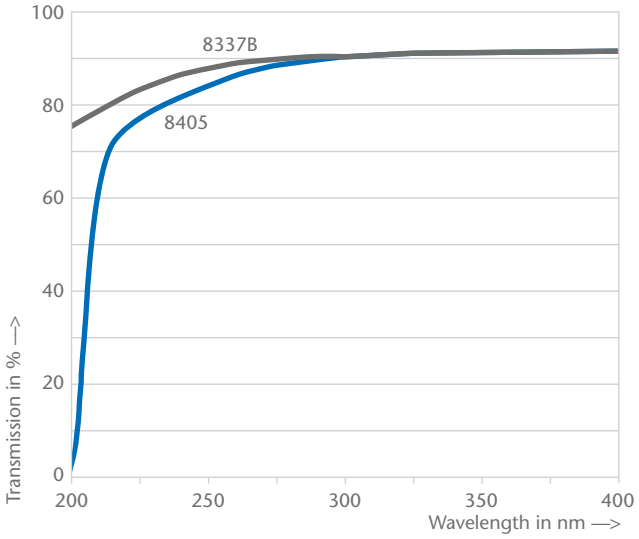



**Fig. 21.** UV transmission of highly UV-transparent technical glass types 8337B and 8405 at 0.5 mm glass thickness

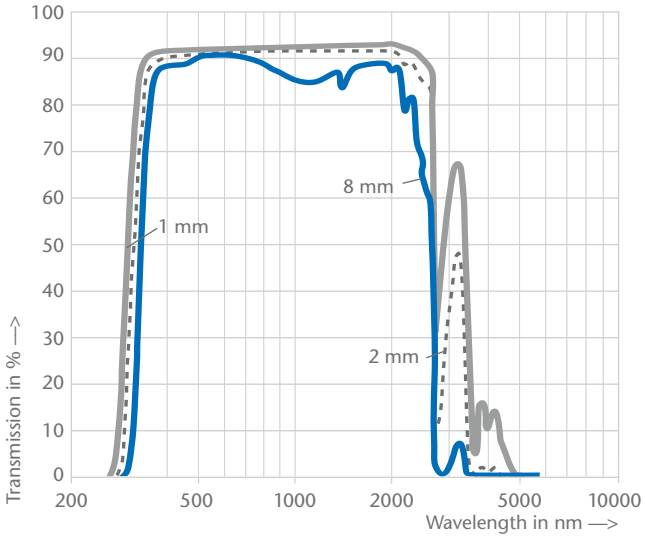



**Fig. 22.** Transmission of DURAN® 8330 for thicknesses 1, 2 and 8 mm

**Optical glass**
The term “optical glass” is used in distinction to “technical glass” for a specific group of glasses mainly for optical applications like imaging in the UV, visible, and infrared wavelength range. These applications require a broad set of glasses with high transmission and well defined refractive index and specific dispersion properties (described by Abbe-numbers). Combinations of these glasses allow for the construction of high-performance optical systems.

Up to 17 or more different raw materials with the lowest level of impurities to avoid absorption by coloring elements are used to achieve the desired specifications. Each optical glass is described (beside others) by its coordinates in the so-called “Abbe-Diagram” (see Figure 50).

**Optical filter glass**
Optical filter glass is known for its selective absorption in certain wavelength ranges. The absorption within the glasses is caused either by ions of heavy metals or of rare earths or it is caused by nano crystals within the glass matrix. By combining different coloring agents a wide range of different filter functions (neutral density filters, longpass filters, short pass filters and bandpass filters) can be obtained. Figure 24 depicts special UV bandpass filters that have a region of high internal transmittance in the UV and high absorption for visible light.

As an alternative to bulk filter glasses, coated interference filters are used. Here a transparent glass substrate is coated with a set of thin transparent layers of e.g. oxidic materials with different refractive indices. The spectral properties of these filters are defined by interference effects.

Optical filter glass and inteference filters are optimized for industrial applications, thus the main focus is the reproducibility of spectral transmittance. However, these glasses appear to be colored if their filter effect lies within the visible light spectrum.

**Chalcogenide glass**
In most known glass types, oxides of e.g. silicon, phosphorous, lanthanum and borate are building the glass forming network. Though some oxidic glass types with special compositions melted under very dry conditions show transmittance until 4–5 microns, the absorption of the cation-O-bond in the network sets a limit to the (mid – far) infrared (IR) transmission of these glasses. The main characteristic of chalcogenide glasses is the complete replacement of the element oxygen by other elements of the chalcogenide group like sulfur, selenium or tellurium to extend transmittance further into the mid to far IR. For instance, SCHOTT IR chalcogenide glasses (IRG) exhibit high transmission from the visible range to beyond 12 µm into the far infrared (see. Figure 23).

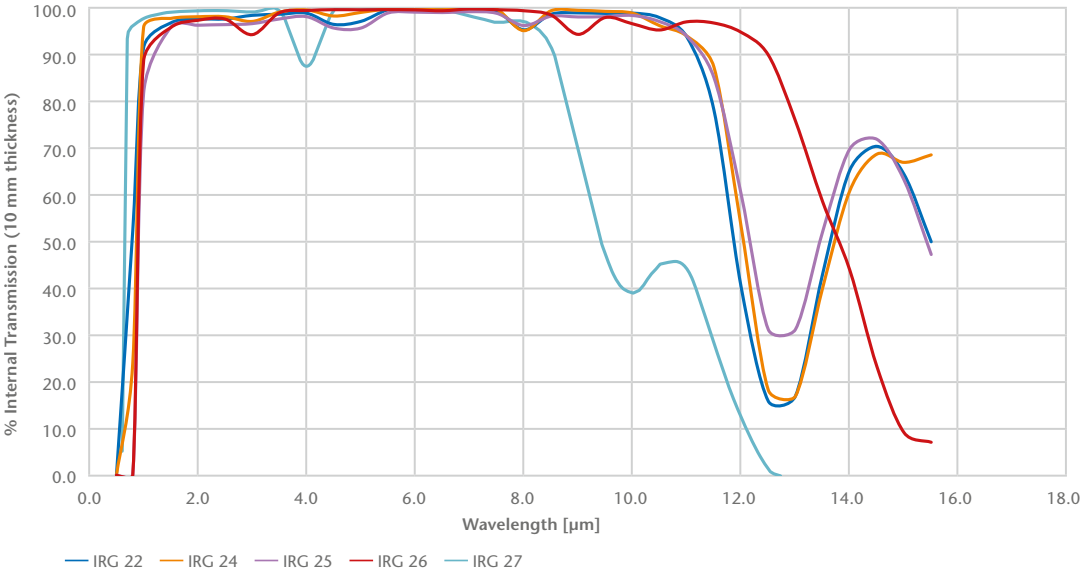



**Fig. 23.** Transmission of IRG 22–27

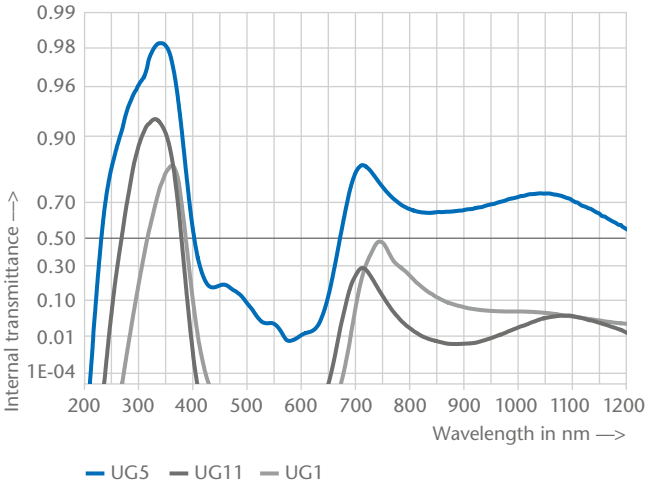



**Fig. 24.** UV bandpass filter for a glass thickness of 1 mm

## 5.4 Color of glass

Color is a sensation perceived by the human eye when observing an illuminated filter glass or incandescent object. The color of glass is a function of its spectral transmission and the spectral energy distribution of the illuminating light source. Color stimulus is measurable and is defined by three numerical values (X, Y, Z) in accordance with color metric conventions set forth by the CIE (see publication CIE N° 15.2 (1986)). The first value is its brightness (standard tristimulus value) Y and the other two values define the color locus. There are two possibilities to define the color locus F (see Figure 25): Either the chromaticity coordinates x and y, or the dominant wavelength $\lambda_d$ (at S) and the excitation purity Pe = DF : DS.

## 5.5 Stress birefringence

Owing to its very structure, glass is an isotropic material. Mechanical stress causes anisotropy which manifests itself as stress-induced birefringence. A ray of light impinging on glass will be resolved into two components vibrating in planes perpendicular to each other and having different phase velocities. After passing through a plate of thickness d which is subjected to a principal stress difference $\Delta\sigma$, an optical path difference $\Delta s$ exists between the two components. This path difference can either be estimated by means of the birefringence colors or measured with compensators:

$$\Delta s = K \cdot d \cdot \Delta\sigma \text{ [nm]}.$$

K is the stress-optical coefficient of the glass (determination according to DIN 52314).

$$K = \frac{\Delta s}{d} \frac{1}{\Delta\sigma} \text{ [MPa}^{-1}\text{]}$$

Many glasses have stress-optical coefficients of about $3 \times 10^{-6}$ MPa$^{-1}$, and borosilicate glasses of up to $4 \times 10^{-6}$ MPa$^{-1}$. High-lead content glasses can have values down to nil or even negative.

Stress-optical measurements permit the determination of permanent stress in glass (state of annealing) as well as of reactive stress caused as a reaction to exterior forces. Stress-optical measurements for the evaluation of glass seals with other glasses, metals, or ceramics are of particular importance. These offer a sensitive method of determining thermal expansion and contraction differences.

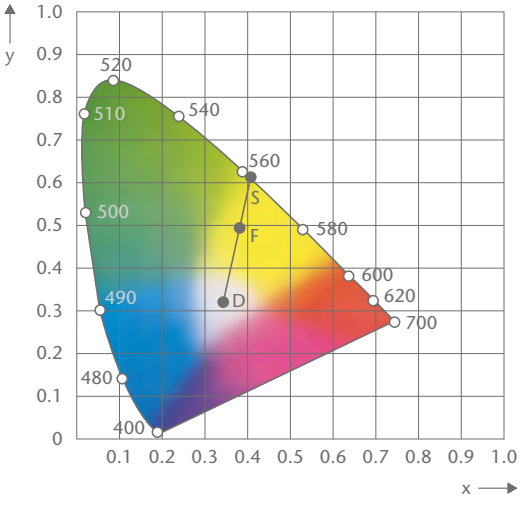
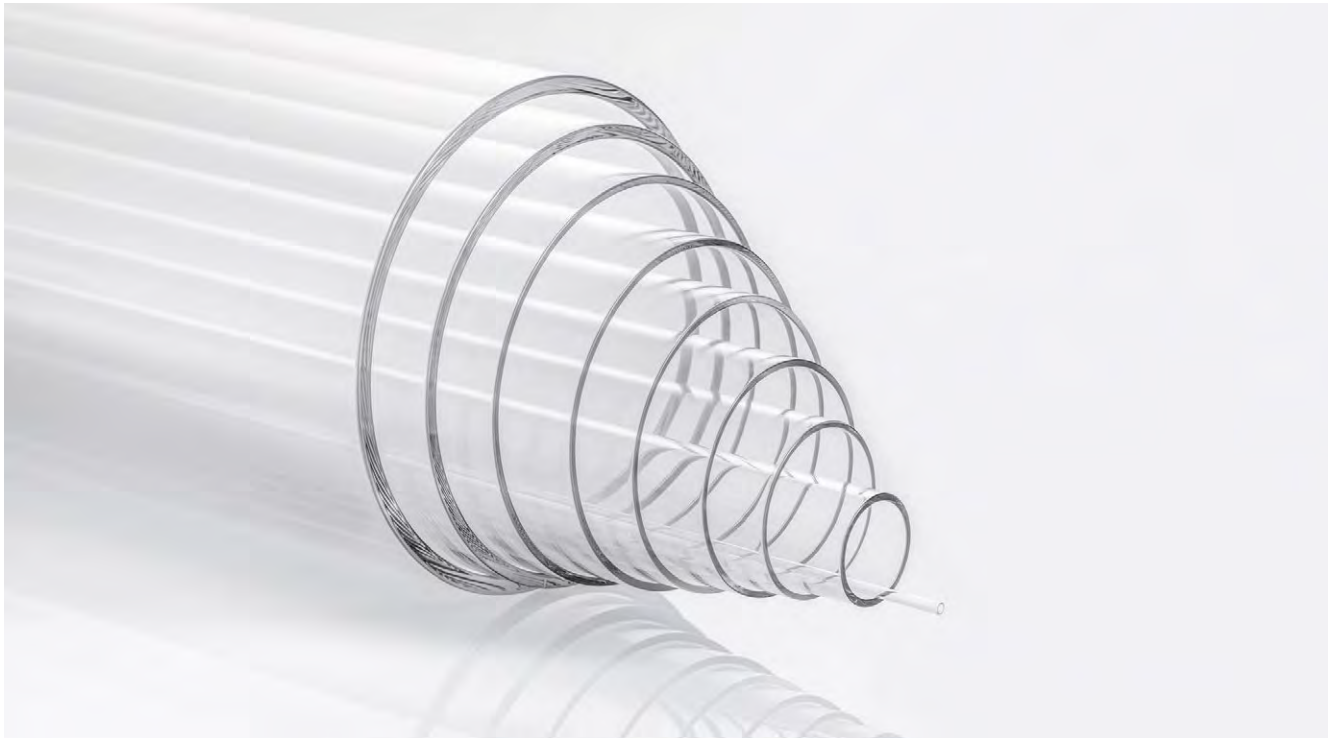



**Fig. 25.** The color of optical filter glasses according to the definition of CIE 1931
D: Color locus of the radiation source, for example D65
S: Point at which the extension $\overline{DF}$ intersects the spectrum locus at $\lambda_d$

# 6. Highly Resistant Glasses for Laboratory, Pharma and ...



DURAN® tubing for a wide range of applications

The chemically resistant glasses categorized as “borosilicate glasses” contain a high percentage of silica (70–80 %), considerable amounts of boric oxide (7–13 %), as well as alkali oxides ($Na_2O$, $K_2O$, 4–8 %), alumina (2–7 %), and sometimes alkaline earth oxides (CaO, BaO, 0–5 %). Characteristically, they have high chemical durability (hydrolytic class 1, acid class 1) and relatively low thermal expansion, giving high thermal resistance and enabling the manufacture of large, thick-walled components from these glasses.

These exceptional properties of borosilicate glasses were recognized by Otto Schott, and large-scale melts were first put to use in 1892.

Chemically durable borosilicate glasses have such a high acid resistance that even for surface areas as large as 400 $cm^2$, exposed to a six-hour boiling in 20 % hydrochloric acid, only very small weight losses can be measured. Because the measurement accuracy in determining the variation in the weight of glasses that have large surface areas is roughly equivalent with the weight losses themselves, a sound comparison between the different glasses of this group is impossible. The values simply indicate high acid resistance.

On the other hand, silicate glasses with higher boric oxide contents (>15 %) are generally not classified as chemically resistant. Examples are electro-technical sealing glasses such as 8245 or 8250, which fall into acid class 4 and 3, respectively.

## 6.1 DURAN®

The coefficient of linear thermal expansion of 3.3 x $10^{-6}$/K is the lowest of all the large-scale mass-produced technical glasses with high chemical resistance. The low specific thermal stress $\varphi$ = 0.24 N/($mm^2$ K) indicates its exceptional resistance to thermal shock and temperature variations. These properties allow the production and hot forming of large, thick-walled articles which can be exposed to application temperatures of up to max. 200 °C.

Its thermal properties coupled with outstanding water and acid resistance make DURAN® a highly suitable material for use in laboratories and large-scale chemical plants, for example as pipelines, reaction vessels, heat exchangers, and so on.

For thin-walled DURAN® items, application temperatures can lie considerably above 200 °C. To guarantee shape stability, a maximum of 500 °C should not be exceeded.

DURAN® is made into tubes of up to 450 mm in diameter and pressed and blown glassware. Processed as flat glass, it is available as a floated product under the tradename BOROFLOAT® 33 and as a rolled sheet glass under the tradename SUPREMAX® for applications in home appliances, lighting, chemical engineering, safety, optics, precision engineering and photovoltaics. Figures 26 and 27 illustrate the chemical resistance.

DURAN® is also available in different shapes and called CONTURAX®.

CONTURAX® Pro profile glass tubing



## 6.2 FIOLAX®

These highly resistant borosilicate glasses are particularly suited for pharmaceutical parenteral packaging such as syringes, ampoules and vials for high-grade injection solutions. Their manufacturing, exclusively in the form of tubes, is today possible with exceptionally tight diameter and wall thickness tolerances. Therefore, the production of syringes, ampoules and vials and their filling on the high-speed filling lines of the pharmaceutical industry are unproblematic. Because the wall thickness of the tubes is comparatively small,

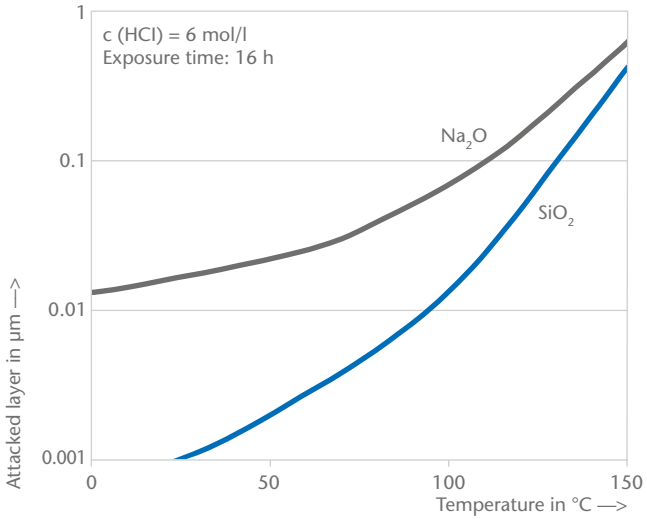



**Fig. 26.** Acid attack on DURAN®/BOROFLOAT® 33/SUPREMAX® 8330 as a function of temperature and calculated from leached amounts of $Na_2O$ and $SiO_2$

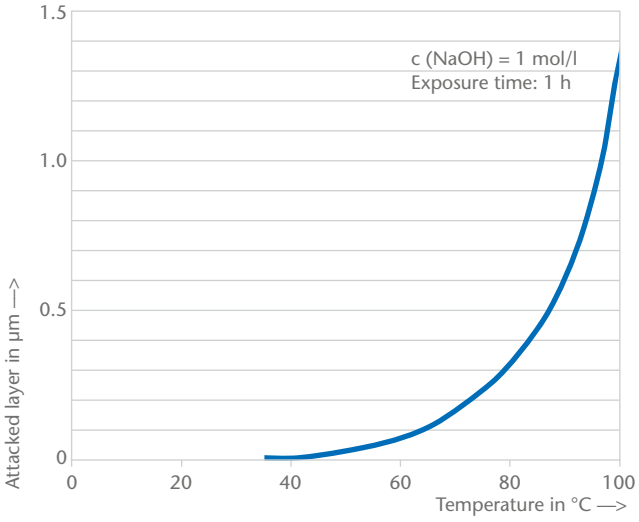



**Fig. 27.** Alkali attack on DURAN®/BOROFLOAT® 33/SUPREMAX® 8330 as a function of temperature and calculated from the weight losses

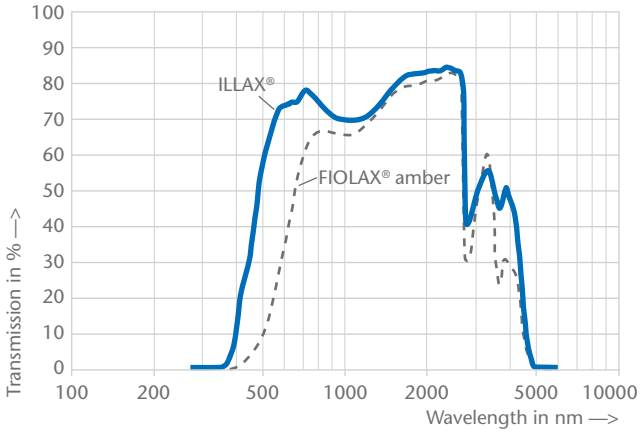



**Fig. 28.** Spectral transmittance of FIOLAX® amber and ILLAX® for 1 mm glass thickness

Syringes made from FIOLAX® neutral glass tubes

thermal stresses in subsequent processing are not critical, despite thermal expansions of $4.9 \times 10^{-6}$/K and $5.4 \times 10^{-6}$/K, respectively.

FIOLAX® tubes guarantee highest quality and outstanding chemical stability. Containers made from these glasses, sometimes also called "neutral glasses," fulfill all the specifications listed in the European Pharmacopoeia and in the various pharmacopoeia of other nations.

| Glass type | Hydrolytic resistance DIN ISO 719<br>Consumption of 0.01 mol/l HCl<br>ml/g glass | Hydrolytic resistance DIN ISO 720<br>Consumption of 0.02 mol/l $H_2SO_4$<br>ml/g glass | Acid resistance DIN 12 116<br>Weight loss<br>mg/dm² | Alkali resistance DIN ISO 695<br>Weight loss<br>mg/dm² |
|---|---|---|---|---|
| DURAN®/BOROFLOAT® 33/ SUPREMAX® 8330 | 0.030 | 0.02 | 0.4 | 136 |
| SUPRAX® 8488 | 0.029 | 0.03 | 0.3* | 92 |
| FIOLAX® clear 8412 | 0.030 | 0.04 | 0.4 | 110 |
| FIOLAX® amber 8414 | 0.030 | 0.04 | 0.6 | 115 |
| PYRAN® S 8341 | 0.033 | n.n. | 0.3 | 130 |

*DIN ISO 1776

**Table 6.** Values of chemical stability

**FIOLAX® clear, 8412**
This glass belongs to the chemically resistant alkaline earth containing borosilicate glass type. Its water and acid resistance correspond to those of DURAN®, and its alkali resistance is even higher. Alkaline preparations up to pH values of 12 can be stored and autoclaved in FIOLAX® clear. General considerations of silicate glasses in alkaline solution from chapter 2.2.3 needs to be considered.

**FIOLAX® amber, 8414**
Due to additions of iron and titanium oxides, this borosilicate glass exhibits high light absorption in the blue and UV spectral regions (see Figure 28). Sensitive pharmaceutical preparations can therefore be effectively protected from light in the critical wavelength region.

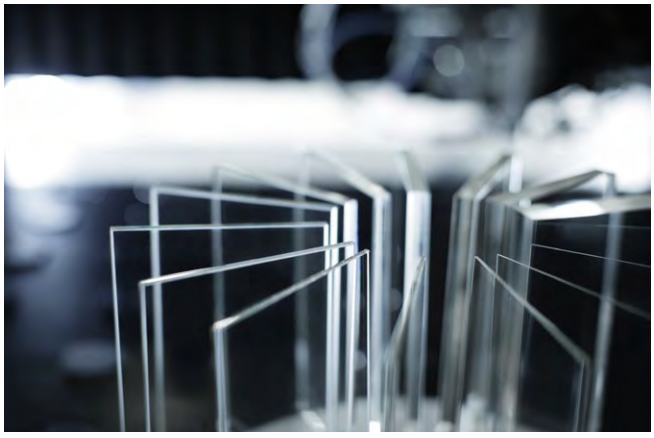
**AR-GLAS®**
AR-GLAS® with a CTE of 9.1 x $10^{-6}$/K belongs to the so-called soda-lime glass family. The hydrolytical resistance is lower compared to the neutral glass FIOLAX® and DURAN® but the glass is still stable enough to be used as a packaging material for non-parental drugs i.e. pipets, vials for tablets, and test tubes. An advantage is good workability and the good price/performance ratio.

## 6.3 BOROFLOAT® 33/SUPREMAX®

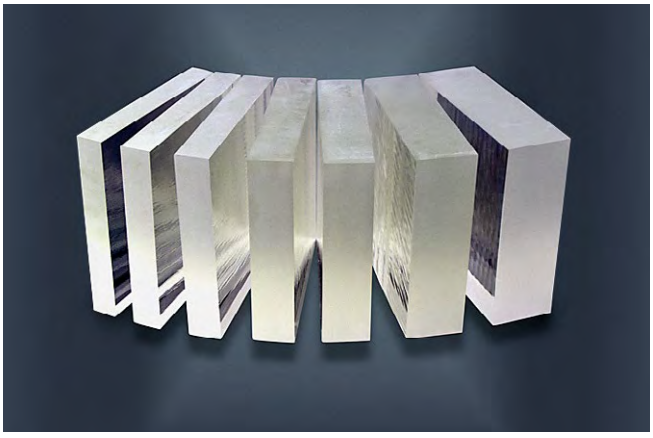
BOROFLOAT® 33 is the world's first floated borosilicate glass. It combines superior quality and excellent flatness with outstanding thermal, optical, chemical and mechanical features. SCHOTT manufactures BOROFLOAT® 33 using Microfloat technology. The Microfloat process delivers highly homogeneous glass quality with a mirror-like surface and excellent flatness. SUPREMAX® is a rolled borosilicate glass that utilizes SCHOTT's unique rolled sheet glass technology to offer thicknesses that cannot be produced via the microfloat process.

The chemical composition of BOROFLOAT® 33/SUPREMAX® complies with the requirements for a typical borosilicate glass according to DIN ISO 3585 and EN 1748 Pt. 1 respectively. Like all borosilicate glasses, BOROFLOAT® 33/SUPREMAX® demonstrate high resistance to water, many alkalis and acids as well as organic substances. Its chemical resistance is superior to that of most metals, even during long-term use and at temperatures in excess of 100 °C (as used as sight glasses in the chemical industry). Exposure to water and acids only results in the leaching out of small amounts of ions from the glass (as used in medicine and analytical engineering).

BOROFLOAT® 33/SUPREMAX® are produced using only the finest natural raw materials and are therefore harmless to human beings and the environment in accordance with the requirements of the European guideline ROHS/2002/95. The glass can be recycled for further use.



The broad range of thicknesses that BOROLFOAT® is available in ensures that it is an ideal enabling material for new and innovative applications



SUPREMAX® is available in a broad range of thicknesses

# 7. Flat Glasses for Home Appliances, Architecture and Safety

AMIRAN® anti-reflective glass

## 7.1 AMIRAN®

SCHOTT AMIRAN® – A clear view of what counts: AMIRAN® anti-reflective glass offers low reflection, superb color fidelity and is nearly invisible – even when there are significant differences in the brightness in front and behind the glass. It reduces reflections to only a fraction compared to conventional glass. This makes AMIRAN® anti-reflective glass the material of choice for display windows and showrooms, museums and glass cabinets, luxury box seating in stadiums and panorama restaurants, television and recording studios, façades and balustrades, lobbies and foyers. The boundaries between the outside and inside disappear. This creates the highest possible freedom of design. Canopies or other constructive measures designed to avoid reflections are no longer necessary.

## 7.2 MIRONA®

SCHOTT MIRONA® – From sight to insight: One glass, two purposes: one moment, MIRONA® translucent, mirrored glass is a stylish, shimmering mirror of silver, and the next, it offers unimpeded views in and out. It's an amazing effect, and unlike other switchable glass products, this effect is produced solely by the coatings applied to MIRONA® mirrored glass. The light level behind the glass determines what you see.

MIRONA® translucent, mirrored glass is a mineral glass that has been coated on both sides. It has low absorption losses and is extremely homogeneous with respect to reflection and transmission. Thanks to its optical interference layer, it has precisely defined states of reflection and transmission. This purely physical principle makes MIRONA® glass an ideal choice to create eye-catching effects.

## 7.3 MIROGARD®

SCHOTT MIROGARD® – Masterful picture glazing: Museums, collections and galleries all over the world have been relying on MIROGARD® anti-reflective glass for decades. This practically invisible glass that features an anti-reflective optical interference coating protects valuable works of art. Without detracting from art enjoyment. Conventional glass reflects approximately eight percent of incident light. And results in undesirable reflections. MIROGARD® glass reduces reflections in the visible spectrum to under one percent and thus allows for an unadulterated view of art. At the same time, MIROGARD® anti-reflective glass is completely neutral in color. This means the brilliance of the glazed artwork remains true to the original and is rendered in its natural colors. Improved UV protection, splinter protection and an easy-to-clean coating are additional features available within the MIROGARD® product portfolio.

## 7.4 PYRAN®, PYRANOVA®, NOVOLAY® secure & PYRANOVA® secure

Fire resistant glazing solutions from SCHOTT act as a barrier against the spread of fire, smoke and heat radiation in the event of fire.

PYRAN® S is manufactured using the micro-float process and clearly outperforms soda-lime glass. Its special physical properties allow for large formats and long fire resistance times.

PYRANOVA® fire resistant glass with heat protection consists of two components: glass and a transparent protective layer between the panes. The layer reacts at approximately and foams up to form an opaque heat shield in case of fire.

Fire resistant glass can also be used for the protection of people and property as an attack-resistant glazing. With NOVOLAY® secure and PYRANOVA® secure, SCHOTT has developed highly effective and compact multifunctional laminates, fulfilling the additional requirements of protection against impact, burglary and bullet penetration.

## 7.5 Processed flat glass for home appliances

SCHOTT® Flat Glass is a thermally toughened (tempered) float glass produced from a variety of raw materials. Due to its particular resistance to thermal shock, temperature gradients and mechanical loads (e.g. bending and impact), SCHOTT® Flat Glass is an ideal component in many applications such as home appliances and commercial cooling.

## 7.6 Special solutions for home appliances

**Easy-to-clean coating SCHOTT® CleanPlus**
SCHOTT® CleanPlus is the industry leading easy-to-clean coating in the market for inner oven door glasses for baking ovens. The coating is resistant against high temperatures as well as mechanical and chemical stress. SCHOTT® CleanPlus is made of a fully tempered, heat-reflective glass and an advanced, easy-to-clean surface. This advanced easy-to-clean coating repels spills and dirt from the inner window surface, allowing it to be cleaned with minimum effort.

**SCHOTT® Energy IR reflective coatings for inner oven door glasses**
SCHOTT® Energy is a range of single and double coated glasses for inner oven doors of conventional or pyrolytic self-cleaning ovens. A durable, non-visible very thin coating on the glass surface reflects heat radiation or reduces the emission of heat from the surface, as a result energy remains inside the oven. Highly efficient, heat-reflecting coatings for inner glasses help to reduce the front temperature of a baking oven and also reduce energy consumption.

**SCHOTT® MetalLook**
SCHOTT® MetalLook provides the ideal solution to combine the look of stainless steel with glass within one surface. It allows a metal-like appearance printed on glass, similar to brushed stainless steel. Easy cleaning and the ability to include very fine and complex graphics are just two of the many advantages offered by this innovative material.

**SCHOTT® Duo Design**
SCHOTT® Duo Design is a new colour technology which offers durable ceramic printing on both rear and front side of the glass. This technology opens up new dimensions for color and haptic effects and offers a wide range of new design possibilities for flat glasses, such as highlighting logos on the front side, combining matt and glossy surface effects, 3D effects as well as tactile guidance via front side printing.

**Features of glass in combination with electronic components**
SCHOTT offers special printing technologies such as heating circuits and capacitive printing to integrate functionality into the glass.

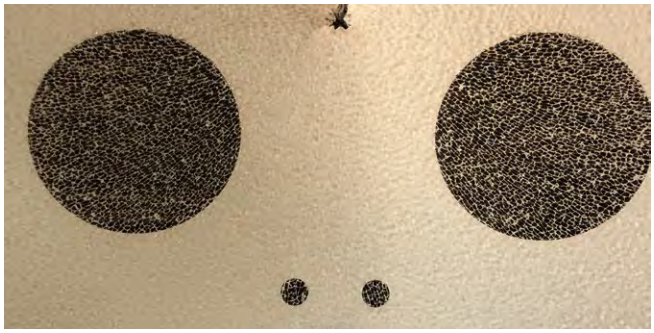
**Heating circuits** are high current circuits which are printed onto the glass. It is a conductive layer which transmits and can be used to apply power circuits onto the glass.

**Capacitive printing** is used for electrical circuits to conduct electricity and can be used for touches on control panels. The conductive layer is printed on the rear side of the glass as an interface for capacitive switches to avoid the assembly of a capacitive foil.

In addition, SCHOTT offers the following features for glasses compatible with electronics: IR transparent printing which lets through infrared waves, haptic printing effect and dead front effect printing.

SCHOTT® MetalLook

SCHOTT® Duo Design



Fragmentation test for a tempered glass

Assembled refrigerator shelf

**Assembly solutions**
SCHOTT offers a broad range of assembly solutions to the home appliance industry including encapsulation and a broad range of assembly solutions combining glass with plastics and metal parts (i.e. for refrigerator shelves, washing machine lids and doors). Solutions to combine glass with lighting are also available.

## 7.7 Insulated glass doors for commercial refrigeration

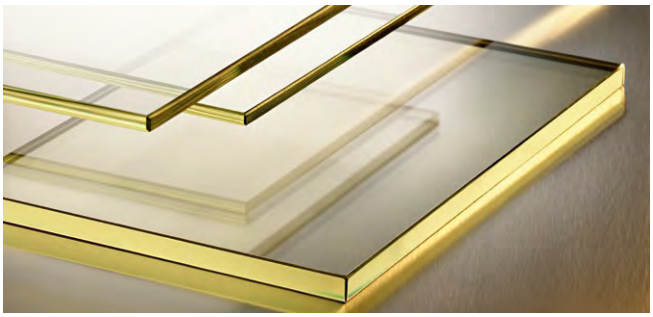
SCHOTT Termofrost® insulated glass door systems are used in a broad range of applications for commercial refrigeration to display and store chilled products down to +2 °C, and frozen goods down to –25 °C. The glass doors typically contain double or triple glazed insulated glass units, the front and rear panes are made of tempered safety glass. SCHOTT Termofrost® glass doors for chiller- and freezer cabinets are designed to display products as attractively as possible. At the same time, they also set new standards for saving space and energy efficiency with up to 60 % energy savings.

## 7.8 Radiation shielding glasses

RD 30® protective clear glass filters are used against e.g. scattered X-rays at mammography work stations. Therefore, the lead equivalent is 0.5 mm Pb. RD 30® can also be used for all other applications in the X-ray area if 0.5 mm Pb is required. RD 30® is a drawn flat glass. The lead oxide content is more than 22 percent by weight. Therefore, a density of above 3.13 g/cm³ is reached, so that 6 mm glass thickness fulfill all legal safety regulations.

Radiation shielding glass RD 50® protects against X-rays and gamma rays in the medical and technical field. RD 50® is an extra dense flint glass. Its protective effect is based on its high content of heavy metallic oxides of nearly 70 percent by weight. The lead oxide content alone is more than 65 percent by weight. Therefore, a density of above 5.05 g/cm³ is reached, so that relatively small glass thicknesses fulfill all legal safety regulations. Radiation shielding glass RD 50® meets the requirements of DIN EN 61331-2.

SCHOTT Termofrost® Smart Access glass door system



SCHOTT radiation shielding glass offers various levels of protection

# 8. Thin Glasses/Ultra-Thin Glasses for Electronics and More

## 8.1 BOROFLOAT® 33

BOROFLOAT® 33 is a premium quality, floated borosilicate glass from SCHOTT. It is recognized worldwide for its outstanding material properties and has become established as one of the key materials used in the electronics and semiconductor industry.

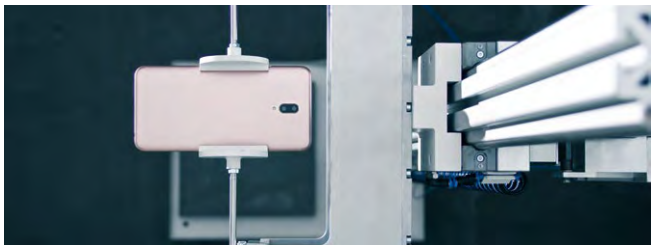
Thin BOROFLOAT® is the glass substrate of choice for a high number of technically challenging applications. With a premium-grade surface quality, a very tight thickness tolerance, an extremely low level of defects and an outstanding level of transparency, BOROFLOAT®'s unique performance characteristics are often decisive in fulfilling the requirements of modern thin glass applications.

BOROFLOAT® 33's coefficient of linear thermal expansion (CTE) matches perfectly with that of Silicon, making it the material of choice for anodic bonding and temporary bonding technologies.

## 8.2 Xensation® 3D

Xensation® 3D is a chemically strengthened lithium aluminosilicate glass that offers an outstanding level of mechanical impact and bending strength, as well as high resistance to scratches. The low transformation point of Xensation® 3D allows thermal bending in the temperature range of ordinary soda-lime glass. This specialty glass has been designed to achieve strength performance levels ideally suited to tough applications – from smartphone to rugged displays to automotive applications to safety glazing.

The unique glass composition combined with more than 130 years' experience in making specialty glass results in one of the most robust and reliable cover glass available today.



For the usage as smartphone cover glass, customers appreciate the outstanding set-drop performance of Xensation® 3D.

## 8.3 Thin glasses

Manufactured in proprietary down-draw and up-draw processes, SCHOTT offers a choice of technical thin glasses with outstanding material properties and pristine surface qualities.

**AF 32® eco** is an alkali-free flat glass available in a thickness range from 0.03 mm to 1.1 mm. Its fire-polished surface has a roughness value below 1 nm. The coefficient of thermal expansion of AF 32® eco matches silicon, therefore it is the perfect choice as optical packaging material in semiconductor related applications. Due to its high transformation temperature, it can be used for high temperature applications up to approx. 600 °C. AF 32® eco is supplied in wafer formats and is manufactured with eco-friendly refining agents.

**D 263® T eco** thin glass is a clear borosilicate glass that has high chemical resistance. It is available in a variety of thicknesses ranging from 0.03 mm to 1.1 mm. D 263® T eco borosilicate glass is available in standard stock size sheets or can be custom cut into round or square shapes. D 263® T eco thin glass is used as substrate glass for coatings in optical interference filters and in touch panel applications in the automotive and electronics industries. D 263® T eco is manufactured with eco-friendly refining agents.

**MEMpax®** is a borosilicate glass which has similar chemical and physical characteristics as the well-known product SCHOTT Borofloat® 33.

At the same time, MEMpax® is produced as wafers in much lower thicknesses of 0.1–0.7 mm and offers thin wafers that no longer need to be ground and polished, thanks to its excellent surface quality.

The coefficient of linear thermal expansion of MEMpax® corresponds with that of silicon, therefore this glass is perfectly suited for use in anodic bonding.

Its low fluorescence, combined with its excellent surface quality, flatness and homogeneity, opens up numerous application possibilities for SCHOTT MEMpax® in MEMS and biotechnology.

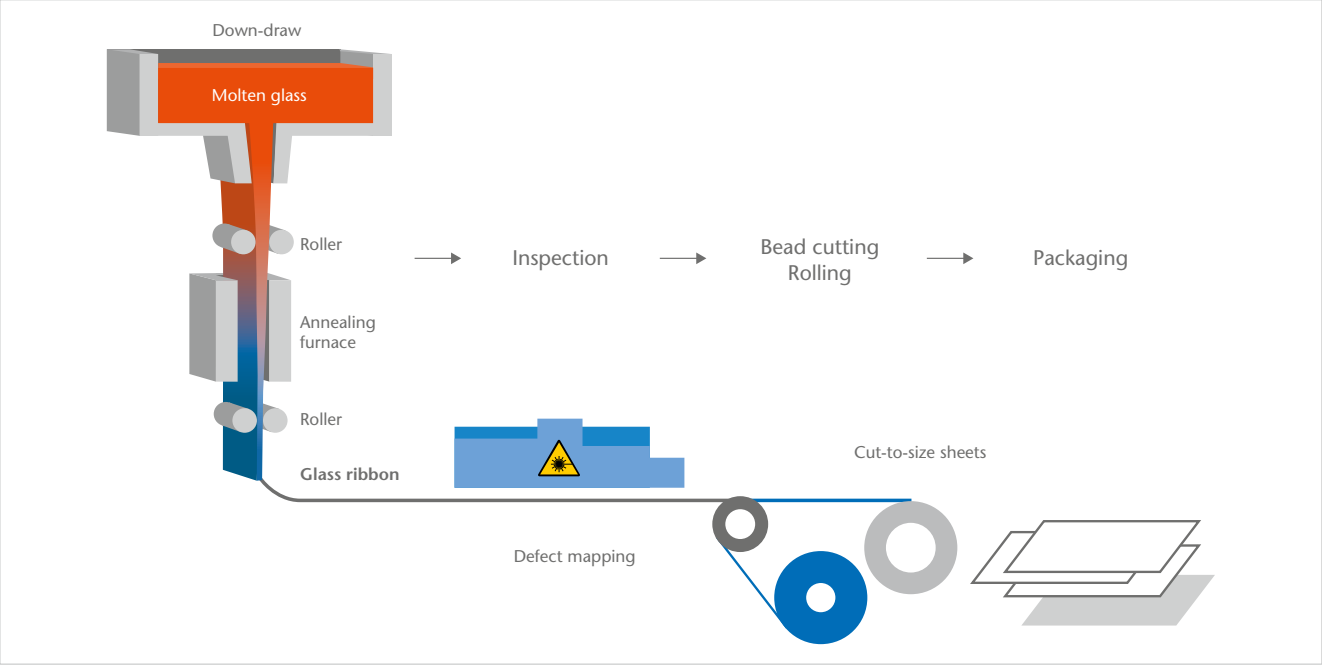



**Fig. 29.** Schematic representation of the production up to the finalized sheet

Thanks to its low alkali content, MEMpax® acts as a high-quality insulator. For this reason, MEMpax® is an extremely appropriate material for applications that require electrical insulation at high temperatures (up to 450 °C). It is manufactured with eco-friendly refining agents.

**D 263® M** is a colorless borosilicate glass for microscopy cover slip applications. It is available in different stock sheet sizes with thicknesses ranging from 0.1 mm to 0.21 mm. D 263® M is a perfect choice as cover glass for microscopic analysis and meets the requirements specified in ISO 8255-1 and DIN ISO 8255-1.

The chemical composition of D 263® M ensures valid and reliable research results due to its low fluorescence and high chemical resistance.

**B 270i®**, is an ultra white low-iron glass manufactured in an up-draw process. It offers high stability with respect to solarization in combination with high transmission in the visible wavelength range. It has a fire-polished surface and high chemical stability. B 270i® is available in a wide range of thicknesses and various in-stock formats. Customized formats (e.g. rounds) and processing can be offered upon request.

**Ultra-thin glass** – the flexibility of the down-draw process technology in terms of thickness has recently introduced the possibility to manufacture ultra-thin glass in the range of 100 down to 20 µm from some of the well-established glass types mentioned above. The production does not require a downstream etching process and is therefore

Ultra Thin Glass for foldable devices

environmentally friendly. The application field of foldable displays shows that ultra-thin glass from SCHOTT can play a decisive role in foldable devices.

The material properties – especially the gas barrier properties – are by far superior to polymer films:

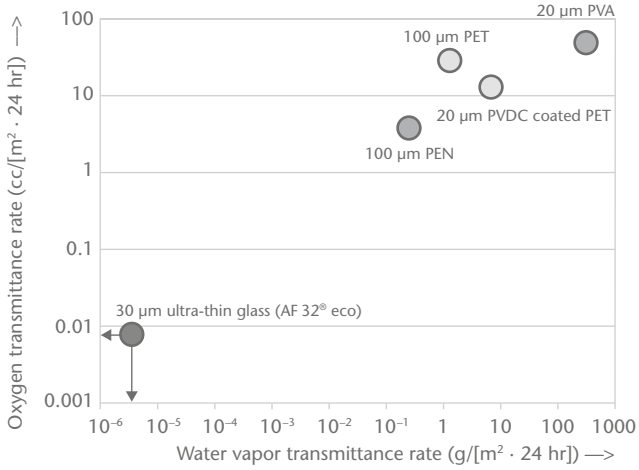



**Fig. 30.** Gas barrier properties of ultra-thin glass

Further material properties of the ultra-thin glass types which are available either on roll or as cut-to-size sheets

| property | D 263 T eco | AF 32® eco |
|---|---|---|
| CTE | 7.2 ppm/K | 3.2 ppm/K |
| alkaline content | low | no |
| transformation point | 557 °C | 715 °C |
| refractive index | 1.5231 | 1.5255 |
| transmission λ = 550 nm, d = 1 MHz | 91.7 % | 91.9 % |
| dielectric constant (at 1 MHz and 20 °C) | 6.7 | 5.1 |
| loss tangent (tan δ) (at 1 MHz and 20 °C) | 0.0061 | 0.0009 |
| thermal conductivity (90 °C) | 1.06 W/(m·K) | 1.06 W/(m·K) |
| glass type | borosilicate | alumin-borosilicate |

**Table 7.** Technical data of relevant materials

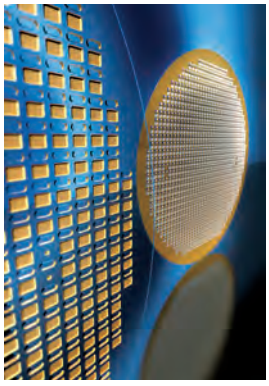
Sample inspection of a thin glass wafer after processing

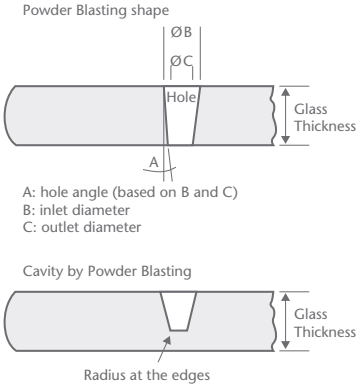
## 8.4 Thin glass processing

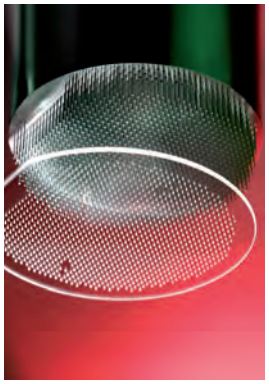
SCHOTT offers an entire portfolio of technologies for processing of thin glass, e.g.

- Cut-to-size for a wide range of wafer and substrate sizes
- Surface refinement by polishing and/or coating
- Structuring of holes or cavities
- Edge treatment options
- Ultrasonic washing
- Clean room packaging

SCHOTT thin glass from a down-draw process does not require any polishing for typical wafer applications due to its inherently pristine surface quality, low roughness and excellent geometry like low total thickness variation. Wafers are directly CNC cut from the mothersheet. Depending on customer requirements, only edge grinding and ultrasonic washing are subsequent processing steps. These wafers are used in high volumes as semiconductor cover glass in wafer level packaging processes of CMOS image sensors for camera modules.





Structured glass wafer

Applications of structured glass wafers and substrates with holes and cavities are in the electronics industry, e.g. for MEMS capping wafers and in the biotech industry, e.g. for flow cells for blood analysis. The two major technologies currently applied by SCHOTT for structuring and their technical capabilities are:

| | Ultrasonic lapping | Powder blasting |
|---|---|---|
| Size | 100 mm to 200 mm | Max. 400 mm x 400 mm |
| Thickness range | 0.4 mm up to 3 mm | 0.05 mm up to 3 mm |
| Different hole configurations | Round holes | Round, rectangular holes and caverns |
| Positioning tolerances | ± 65 µm* | ± 65 µm* |
| Min. hole diameter | 0.4 mm | 0.1 mm |

*Tighter tolerances upon request

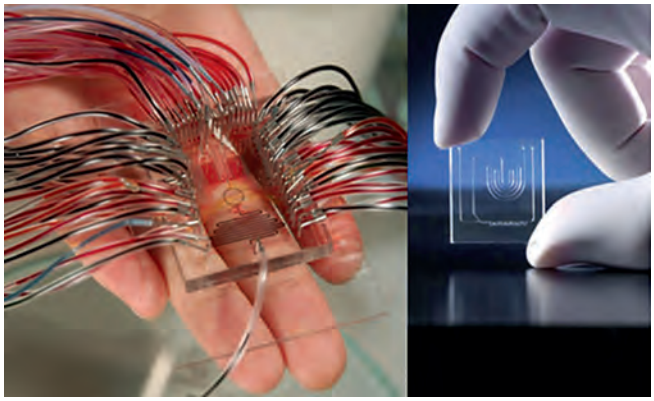
**Table 8.** Structured technologies and technical capabilities

For processing of ultra-thin glass, new laser-based processes are under design to cut the glass but also to generate a high number of holes with diameters around 50 microns as TGVs (through glass vias) in printed circuit board and interposer applications.

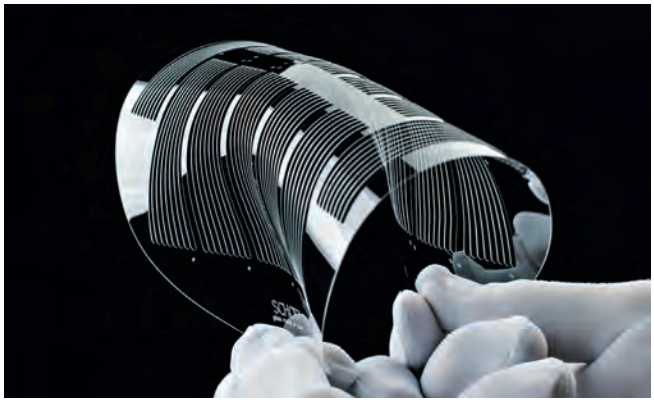
**Flexinity**

Structured thin or ultra-thin glass wafers are used as a substrate for sensors, batteries and diagnostic technology. The FLEXINITY® portfolio of structured glass solutions enables new applications and further miniaturization of electronics through thinner glass wafers and structures that are more precise. The technology offers the lowest structuring radius of just 150 micrometers (µm) and a feature size tolerance lower than ± 10 µm. The structured wafers are available from the diverse assortment of glass types found in SCHOTT's down-draw portfolio as well as the plano-plano-processed borosilicate glass – BOROFLOAT® 33.





Flow cell for DNA analysis, structured into SCHOTT thin glass



Flexinity® – Structured glass solutions

## 8.5 Anti-reflective glasses for technical applications (CONTURAN®/DARO)

### 8.5.1. CONTURAN®

CONTURAN® is an anti-reflective coating on one or both surfaces based on optical interference coatings, which can be used for technical applications i.e. front panels of visual display units, touch displays, televisions, display panels, public displays.

The multilayer coating is applied by way of a sol gel process that uses dip coating technology. As shown in Fig. 31a, three different layers are subsequently formed simultaneously on both surfaces of the glass. The refractive index of the layers is varied by the composition of the sol gel solution. $SiO_2$ is used as a low index material and $TiO_2$ for the high refractive index. In standard float glass, without an interference coating, about 8 % of light is reflected backwards to the observer (Fig. 31b, lower picture). The interference coating creates a design, which reduces reflecting light waves significantly. As shown in Fig. 31b, less than 1 % of light is now reflected. This reduction of the reflection leads to an enhanced contrast for pictures or displays behind CONTURAN® cover glass.

The coating is designed to reduce the reflection in the visual wavelength region of approximately 400 to 700 nm. Fig. 32 shows the reflection curve for two distinctive coating designs used in the CONTURAN® product portfolio. The “green hue” coating is a design used in standard optics. The “blue hue” coating yields a distinct residual blue reflection often desired in technical, design-oriented applications.

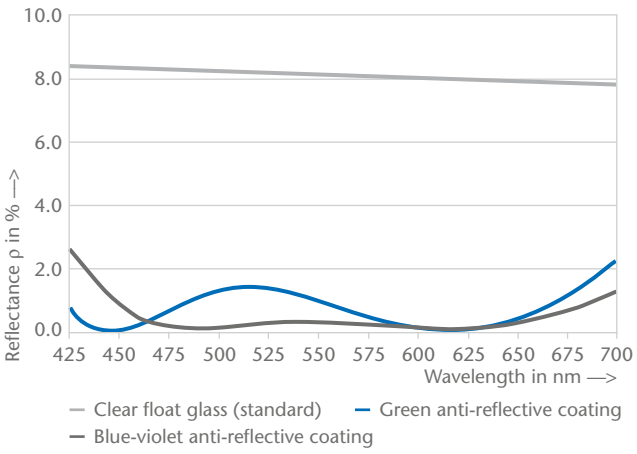



**Fig. 32.** Reflection spectrum of CONTURAN®: Comparison of “blue hue” and “green hue” reflection

### 8.5.2. Applications of CONTURAN®

Mineral-based cover glasses are often used in display applications to protect the display from mechanical damage. However, the reflection of light on the glass reduces the contrast of the display, especially when used outdoors. One of the most obvious examples is the usage of smartphone outdoors, where the excellent display performance often is completely wiped out by the sunlight. CONTURAN® with its low reflection is exactly designed to maintain the contrast of the display by reducing undesired reflections. Popular examples for applications are public transportation displays, digital signage and professional displays used for automatization or in the medical sector.

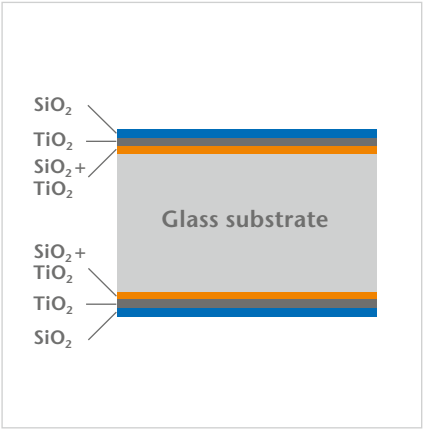



**Fig. 31a.** Three layer coating design

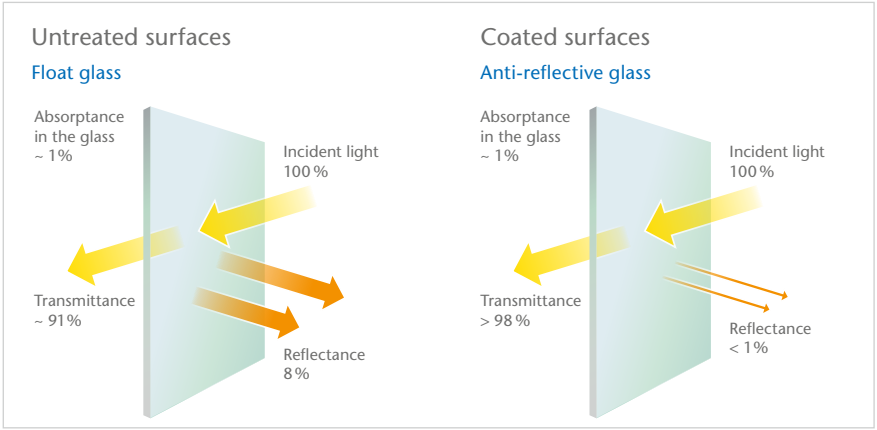



**Fig. 31b.** Effect of anti-reflective coatings on the reflection of light

Applications of CONTURAN®: public transportation displays, digital signage and professional displays used for automatization or in the medical sector.

Since CONTURAN® can be processed in the same way as regular flat glass, all design opportunities can be applied. Different shapes, edge processing and even complex contours can be achieved. Safety standards for automotive and building standards are fulfilled using tempered or laminated CONTURAN®.

### 8.5.3. CONTURAN® DARO

In order to use an AR coating in a touch application, it must have an oleophobic coating that can stand up to hundreds of thousands of finger touches and rubs. CONTURAN® DARO keeps its properties such as reduced visibility of finger prints, easy-to-clean properties and good haptics even if subjected to harsh chemical stress.

**DARO** is a coating designed to enhance the user experience of anti-reflective coated displays by eliminating the disturbing visual impression of finger prints. **DARO** stands for **D**urable **A**nti **R**eflective **O**leophobic coating and yields an organic coating on top of CONTURAN® with unique, long lasting anti finger print (AFP) behavior.

Unique advantages created by the DARO coating:

**Reduced visibility of finger prints:** The oleophobic nature of the coating repels the fatty substances of a finger print and hence leaves less material on the surface: This yields a dramatic reduction of the visibility of the finger prints as shown in the comparison in Figure 33.

**Fig. 33.** Visual appearance of a finger print on **CONTURAN®** (right) and on **CONTURAN® DARO** (left)

**Easy to clean properties:** The hydrophobic behavior of DARO, which can be seen in the Figure 33 as a round water droplet, leads to an easy-to-clean effect. Dry wiping of the surface is normally sufficient to remove dirt and traces of finger prints.

Using a dry cheesecloth rub test according to MIL-C-675C (3/8 inch pad of dry laundered cheesecloth, load 1.5 lbs., cheesecloth exchanged after 10,000 cycles each), the coating proves to be durable in excess of 450,000 rubs and still maintains its high contact angle, as shown in Fig. 34, well surpassing the result of a standard AFP coating on the market today. In addition, a **neutral salt water spray test** reflects the typical chemical challenge imposed by the sodium content of finger prints. DARO has proven to be extremely long lasting and can withstand more than 90 days in a salt water spray test according to ASTM B117-73 and EN ISO 9227-NSS (Temperature 35 °C +/–2 °C, salt concentration 5 % +/–1 %). Fig. 35 shows the result of the contact angle, which still is above 90° after 90 days of test duration.

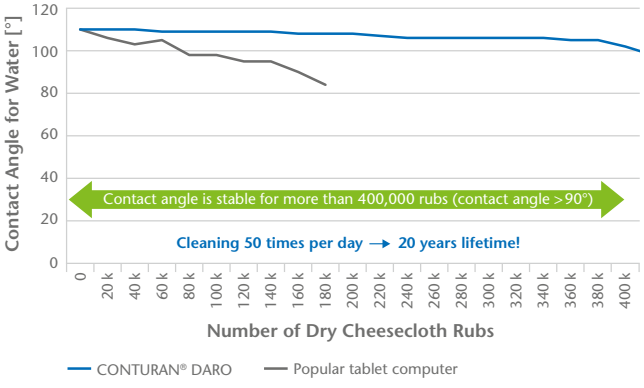



**Fig. 34.** Contact angle of DARO after multiple cheese cloth wipes

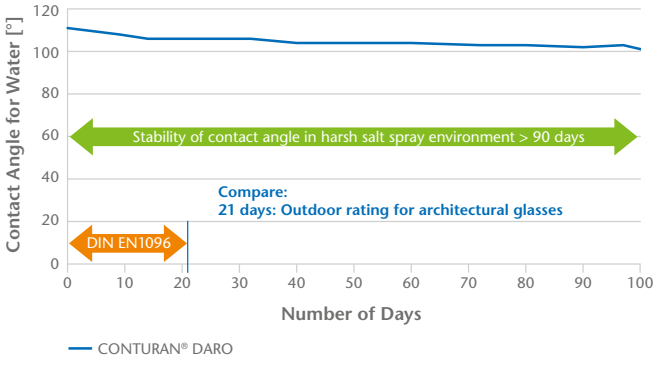



**Fig. 35.** Contact angle of DARO after long term exposure in EN ISO 9227-NSS test

Applications of CONTURAN® DARO: information displays

# 9. Glasses for Joinings

## 9.1 Sealing glasses

### 9.1.1 General information

Glasses are best suited for the production of mechanically reliable and vacuum-tight fusion seals with metals and ceramics. Particularly favored properties are the viscosity behavior of glass and the direct wettability of many crystalline materials by glasses.

A necessary condition for the stability and mechanical strength of glass seals is the limitation of mechanical stress in the glass component for temperatures encountered during production and use. To ensure "sealability" (which means that the thermal contractions of the two sealing components match each other below the transformation temperature of the glass), glasses of a special composition, so-called sealing glasses, are often developed. Apart from sealability, such glasses must very often fulfill other requirements such as high electrical insulation, special optical properties, etc. The sealability can be tested and evaluated with sufficient accuracy and certainty by stress-optical measurements in the glass portion of a test seal (ISO 4790).

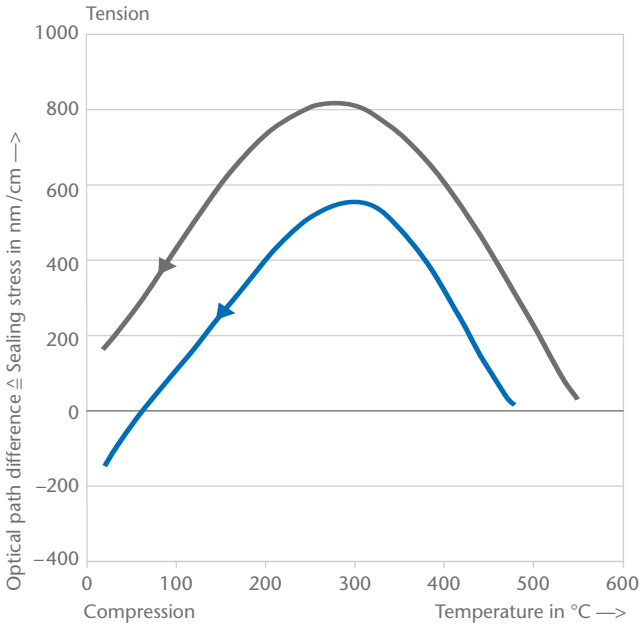



**Fig. 36**. Influence of cooling rate on the temperature–sealing stress relationship in a 8516–52 Ni/Fe combination; blue curve: low cooling rate, black curve: high cooling rate

Reed switches encapsulated in SCHOTT glass type 8516

Apart from characteristic material values such as coefficient of linear thermal expansion, transformation temperature, and elastic properties, the cooling rate (Figure 36) and the shape can also have considerable influence on the degree and distribution of seal stresses.

### 9.1.2 Matching glasses

In reference to the expansion coefficients of technically applied sealing metals (e.g. tungsten and molybdenum) and alloys (of Ni-Fe-Co, Ni-Fe-Cr, and other special materials), the corresponding sealing glasses are grouped and designated as "tungsten sealing glasses," "Kovar glasses," etc. (see Table 9).

Alkaline earth borosilicate glasses (8412) and aluminosilicate glasses (8252, 8253) have the necessary sealability and thermal resistance to be particularly suitable for tungsten and molybdenum sealings frequently used in heavy-duty lamps.

Tungsten is very often used as a metal wire for highly developed and highly stressed seals. For this, a group of glass types with additional properties are available (8487).

Ni-Fe-Co (Kovar) alloys are of great importance as substitutes for molybdenum. Suitable glasses (8245 and 8250) characteristically contain relatively high amounts of $B_2O_3$. These glasses have additional special properties, such as high electrical insulation, low dielectric loss and low X-ray absorption, and meet the most stringent requirements for vacuum tube technology and electronic applications.

| Metal ($\alpha_{20/300}$ in $10^{-6}$/K) | Glass no. | Glass characteristics | Main applications |
|---|---|---|---|
| Tungsten (4.4) | 8337B | borosilicate glass, highly UV-transmitting | photomultiplier, UV-detectors |
| | 8487 | high boron content, low melting temperature | flash lamps, lamp bulbs, exhaust and flare tubes, discharge lamps |
| | 8689 | borosilicate glass, high UV-blocked, stabilized against solarization | backlights |
| Molybdenum (5.2) | 8252 | alkaline earth aluminosilicate glass, free from alkali | halogen lamps |
| | 8253 | alkaline earth aluminosilicate glass, free from alkali, high temperature resistance | halogen lamps |
| Molybdenum and 28 Ni/18 Co/Fe (5.1) | 8242 | Borosilicate glass, electricity highly insulating | clad tube for optical fibers |
| | 8245 | high boron content, low melting temperature, low x-ray absorption | x-ray tubes, photomultiplier |
| | 8250 | high boron content, low melting temperature, high electric insulation, low dieelectric losses | transmitting tubes, image converters clad tubes for optical fibers, x-ray tubes, glass-to-metal seal packages |
| | 8270 | high boron content, stabilized against Tyndall | backlight beads |
| 28 Ni/23 Co/Fe (7.7) | 8436 | alkali alkaline earth silicate, sealable with sapphire, resistant to Na vapor and alkalis | |
| 51 Ni/1Cr/Fe (10.2) | 8350 | soda-lime silicate glass, AR-GLAS® | |
| Cu-sheathed ($\alpha_{20/400}$ radial 99) ($\alpha_{20/400}$ axial 72) | 8531 8532 8360 | dense-lead silicate, Na- and Li-free, low melting temp., high electrical insulation | low-temperature encapsulation of diodes |
| 52–53 Ni/Fe (10.2.–10.5.) | 8516 | containing FeO for hot forming by IR, low volatilization, lead-free | reed switches |

**Table 9.** Special properties and principal applications of technically important sealing glasses, arranged according to their respective sealing partners

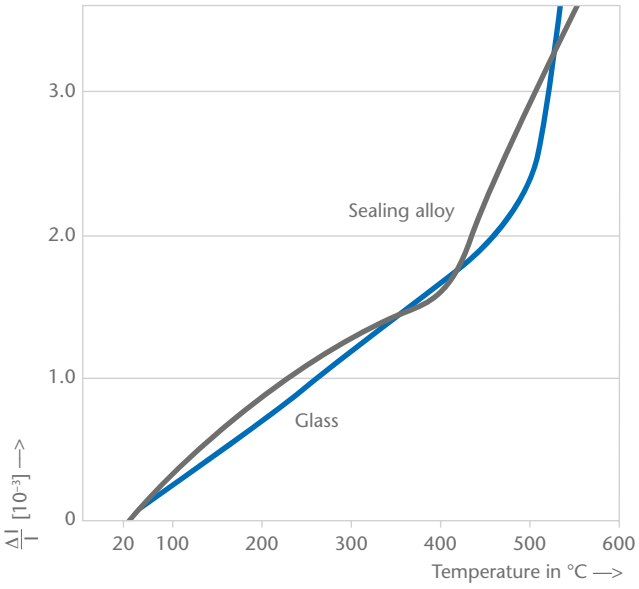



**Fig. 37.** Relative thermal expansion of the components of a matched glass-to-metal seal (glass 8250 – NiCo 2918)

For Ni-Fe-(Cr) alloys, which are frequently used in technical applications, but also for copper-sheathed wire, glass groups belonging to the soft glass category are recommended. Such glasses usually meet certain special requirements, such as high electrical insulation (alkali-lead silicate 8095), exceptionally low working temperature (dense-lead glasses 8531, 8532), etc.

FeO-containing glass (8516) is frequently used for hermetic encapsulation of electrical switches and electronic components in inert gas. Hot forming and sealing are easily achieved by absorption of IR radiation having its maximum intensity at 1.1 µm wavelength (Figure 38). The presence of a portion of $Fe_2O_3$ makes these glasses appear green. At appropriately high IR intensities, they require considerably shorter processing times than flame-heated clear glasses.

### 9.1.3 Intermediate sealing glasses

Glasses whose thermal expansion differs so widely from that of the partner component that direct sealing is impossible for stress reasons, must be sealed with intermediate sealing glasses. These glasses are designed for the recommended seal transitions in such a way that the sealing stresses do not exceed 20 N/mm² at room temperature.

| Glass no. | Sealing partners | $\alpha_{20/300}$ | Transformation temperature | Glass temperature at viscosities | | | Density | $t_{k100}$ |
|---|---|---|---|---|---|---|---|---|
| | | | | $10^{13}$ dPa·s | $10^{7,6}$ dPa·s | $10^{4}$ dPa·s | | |
| | | [$10^{-6}$/K] | [°C] | [°C] | [°C] | [°C] | [g/cm³] | [°C] |
| 8228 | Fused 8229 | 1.3 | 700 | 700 | 1135 | 1665 | 2.15 | – |
| 8229 | 8228, 8230 | 2.0 | 600 | 637 | 930 | 1440 | 2.17 | 350 |
| 8230 | 8229, 8230 | 2.7 | 570 | 590 | 915 | 1425 | 2.19 | 255 |
| 8447 | 8449, 8486, 8412, 8250, 8245, Kovar | 4.6 | 475 | 505 | 720 | 1045 | 2.26 | 270 |
| 8448 | 8330, 8449, 8486, 8487, Wolfram | 3.8 | 510 | 560 | 800 | 1210 | 2.25 | 265 |
| 8449 | 8448, 8412, 8447, 8487 | 4.5 | 535 | 550 | 785 | 1150 | 2.29 | 350 |
| GS10 | Fused silica, GS20 | 1.25 | 700 | 730 | 1195 | 1710 | 2.17 | 420 |
| GS20 | GS10, GS25, GS30 | 1.9 | 690 | 730 | 1175 | 1680 | 2.22 | 465 |
| GS25 | GS20, GS30 | 2.65 | 610 | 640 | 1055 | 1605 | 2.21 | 440 |
| GS30 | GS20, GS25, 8330 | 3.05 | 620 | 635 | 1055 | 1570 | 2.24 | 440 |

Note: type designation of the ceramics to DIN 40685;
manufacturer of Vacon-alloys: Vacuumschmelze Hanau (VAC)

**Table 10.** Sealing and intermediate sealing glasses

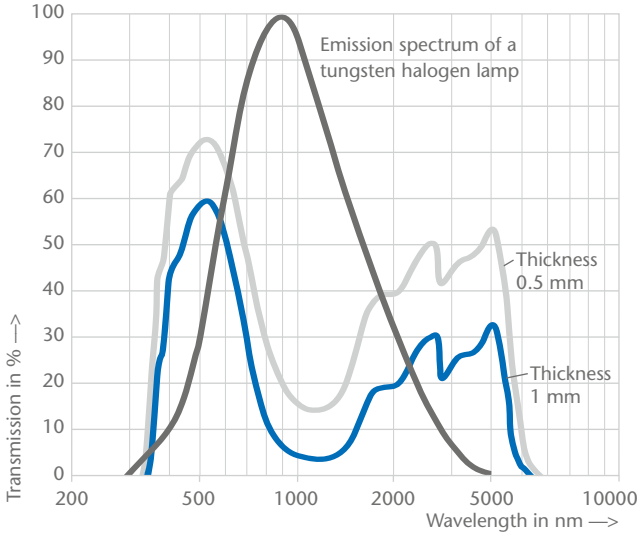
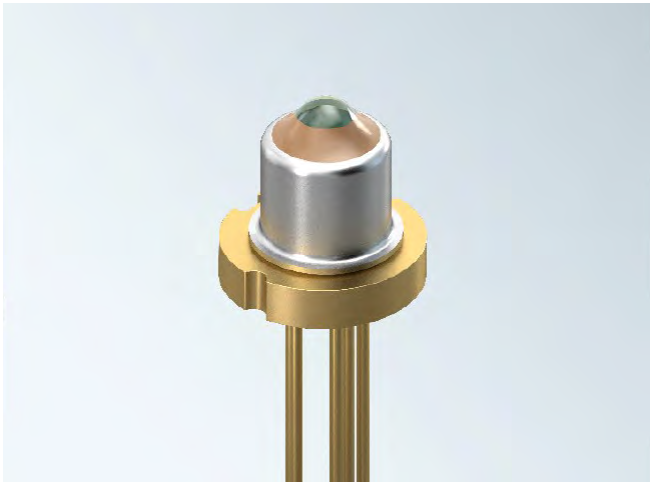
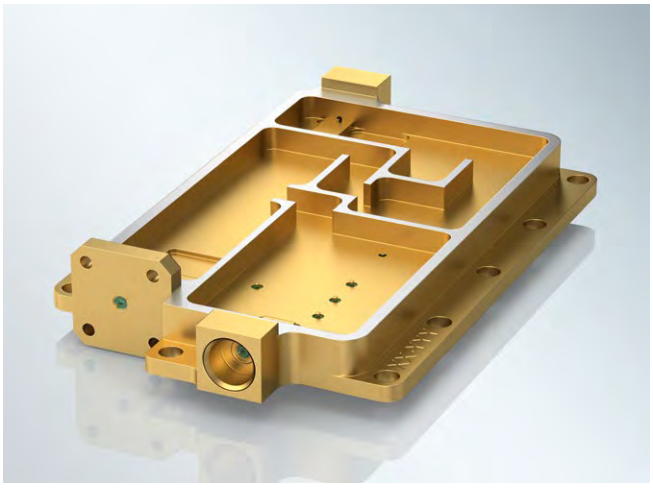



**Fig. 38.** IR absorption of Fe-doped glasses compared to the emission of halogen lamps. Transmission of reed glass 8516, thicknesses 0.5 mm and 1 mm, and emission of a tungsten halogen lamp (3000 K, rel. unit)





Glass-to-metal sealed housings and feedthroughs reliably protect sensitive electronics in harsh conditions such as humidity, temperature fluctuations, pressure or aggressive chemicals.

### 9.1.4 Compression seals

A common feature of all compression seals is that the coefficient of thermal expansion of the external metal part is considerably higher than the thermal expansion coefficients of the sealing glass and the metallic inner conductors. As a result, the glass body is under overall radial pressure after the sealing. This prestressing protects the glass body against dangerous mechanical loads and guarantees robust, mechanically insensitive seals. Because the compressive stress of the glass is compensated by tensile stress in the jacket, the jacket wall must be sufficiently thick (at least 0.5 mm even for small seals) in order to be able to absorb such tensions permanently. Like adapted seals, compression seals can be produced as hard glass or soft glass seals. If the difference of the thermal expansion of the metallic jacket and the sealing glass is significantly higher than 5 ppm/K, an additional prestressing of the glass body results ("reinforced compression seal"); see Figure 39.

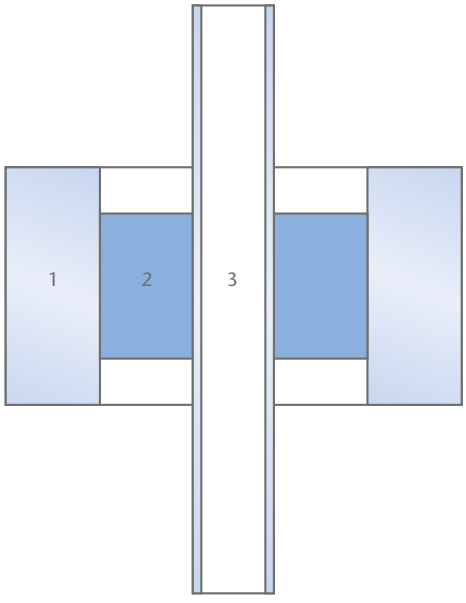



**Fig. 39**. Schematic representation of a compression glass-to-metal seal
1 = external lead, 2 = glass, 3 = internal tubular lead

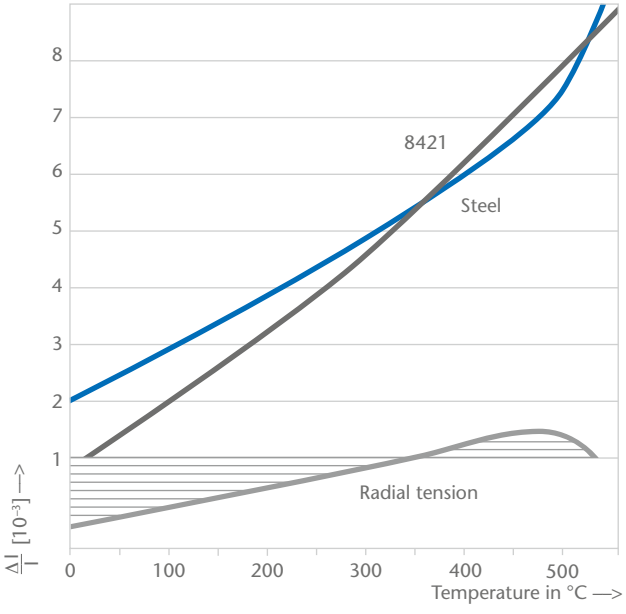


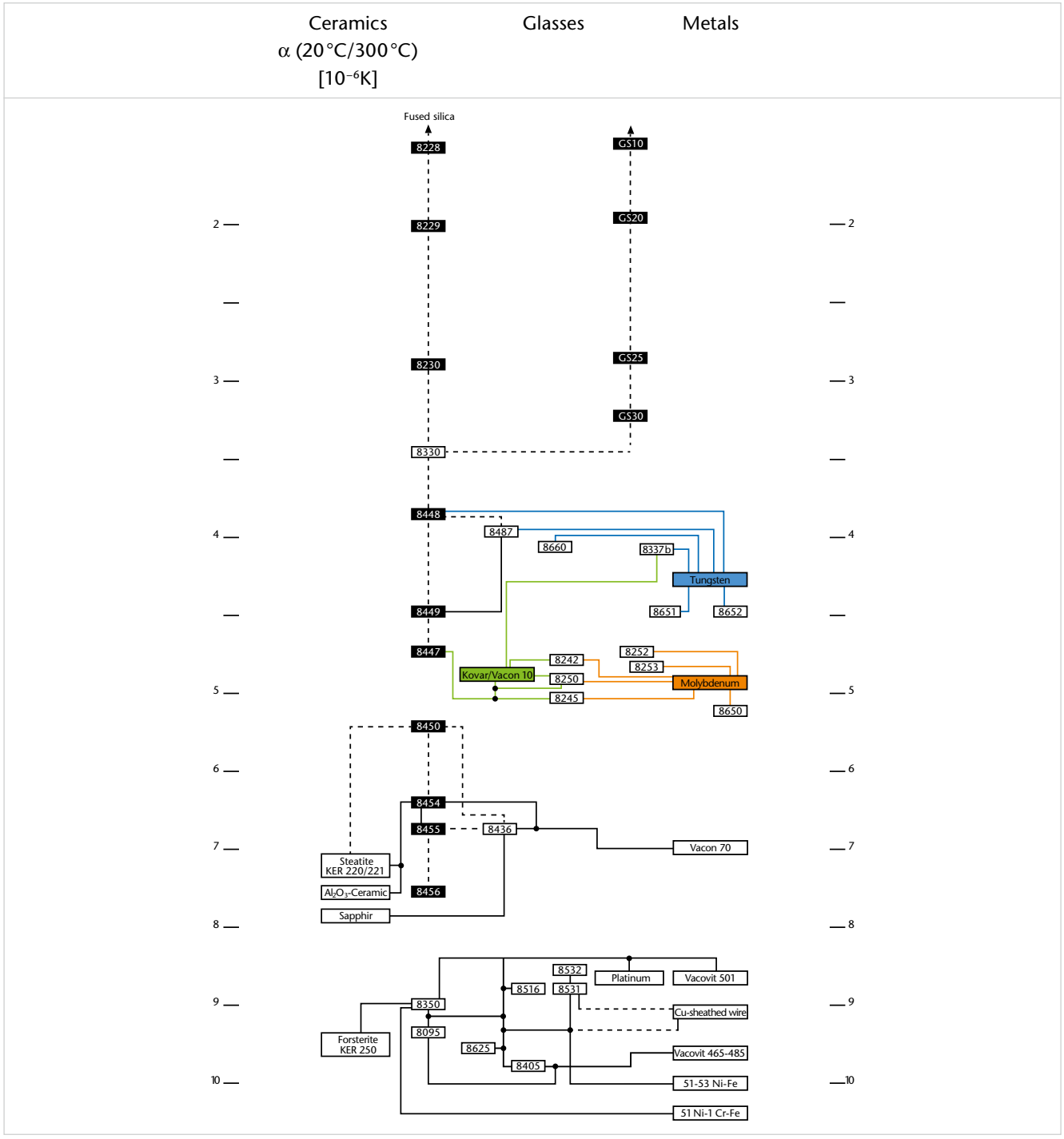

**Fig. 40**. Relative thermal expansion of the glass and metal (compression ring) of a compression glass-to-metal seal

| Designation | $\alpha_{(20/300)}$ [$10^{-6}$ $K^{-1}$] | | |
|---|---|---|---|
| | Compression ring | Glass | Interior lead |
| Standard compression glass-to-metal seals | 13 | 9 | 9 |
| Low-expansion standard compression glass-to-metal seals | 9 | 5 | 5 |
| Reinforced compression glass-to-metal seals | 18<br>13 | 9<br>5–7 | 9<br>5 |

**Table 11.** Expansion coefficients of common material combinations for compression glass-to-metal seals

| Glass no. | Main applications | $\alpha_{(20/300)}$ | Transformation temperature Tg | Glass temperatures in °C at viscosities dPas | | Density | $t_{k100}$ | log of the electric volume-resistivity in Ω cm at | | Dielectric properties at 25 °C for 1 MHz | | Chemical resistance classes | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | [$10^{-6}$ 1K] | [°C] | $10^{7,6}$ | $10^4$ | [g/cm³] | [°C] | 250 °C | 350 °C | DZ | tanδ [$10^{-4}$] | Water | Acid | Alkaline Solution |
| 8350 | Compression seals Seals with steels and NiFe alloys | 9.0 | 520 | 708 | 1035 | 2.52 | 198 | 7.1 | 5.7 | 7.2 | 70 | 3 | 1 | 2 |
| 8421 | Compression seals Seals with steels and NiFe alloys | 9.6 | 525 | 721 | 1000 | 2.59 | 253 | 8.1 | 6.4 | 7.4 | 43 | 3 | 3 | 2 |
| 8422 | Compression seals Seals with steels and NiFe alloys | 8.6 | 540 | 722 | 1027 | 2.46 | 212 | 7.3 | 5.8 | 7.3 | 60 | 2 | 3 | 3 |
| 8629 | Compression seals Seals with steels and NiCo 2918 | 7.6 | 529 | 720 | 1020 | 2.52 | 267 | 8.3 | 6.7 | 6.4 | 26 | 1 | 3 | 2 |
| 8630 | Compression seals Seals with steels and NiFe alloys, increased requirements for electrolytic resistance and temperature stability | 9.1 | 440 | 660 | 975 | 2.53 | 317 | 9.3 | 7.6 | 6.5 | 21 | 3 | 1/2 | 2 |

**Table 12.** Sealing glasses for compression seals




Technical glasses

Intermediate sealing glasses

Producible seals, limited with regard to size and geometry, with stresses between 8 N/mm² and 20 N/mm² at room temperature

Tried-out, unrestricted seals with stresses ≤8 N/mm² at room temperature

**Table 13.** Graded seals

## 9.2 Glass and glass-ceramic sealants for high temperature applications

Due to their good compatibility to refractory materials, special glasses and glass-ceramics are excellent candidates to enable stable high temperature resistant joinings. This class of materials is characterized by transition temperatures exceeding 500 °C and high electrical resistance. Glasses, which undergo crystallization, can even be used above their original glass transition temperature. Glasses exhibiting a high amorphous glass phase show favourable "self-healing" characteristics. Sealings can be achieved through conventional heating (in a furnace) as well as through laser sealing.

**Advantages of HT (high temperature) and SOFC (Solid oxide fuel cell) sealing glasses**

- Mechanical stability in challenging thermal cycling conditions, achieved by perfectly matching the CTE to the interconnects and ceramic components in SOFC, as well as to $Al_2O_3$, $ZrO_2$ and SiC substrates
- Reliable gas-tight seal at elevated temperatures
- Excellent electrical insulation due to alkaline free sealing materials

**Application examples**

- High temperature sensors and technical ceramics:

  Aluminum oxide, zirconium oxide and silicon carbide exhibit high temperature resistance and are commonly used in high-temperature sensor applications i.e. in the combustion chamber or exhaust track of automobiles.

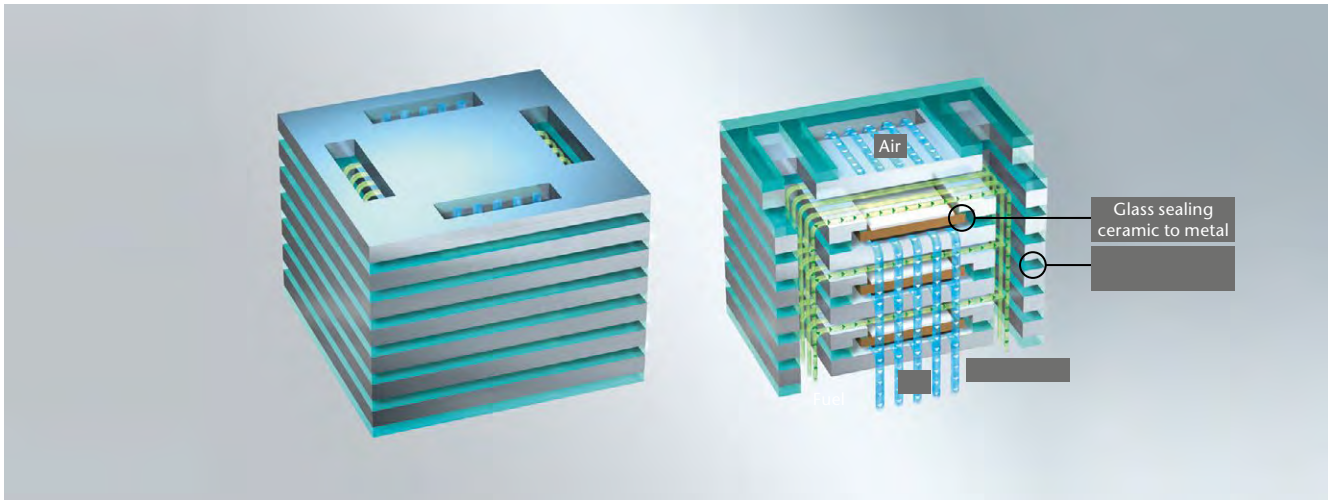
  SCHOTT has developed special glasses and glass-ceramics for the joining of these technical ceramics alone or in combination with different alloys. The sealants are stable at elevated temperatures and chemically resistant, thereby contributing to the stability of the ceramic applications over an extended period of time.

- Solid oxide fuel cells (SOFC) / solid oxide electrolyzer cells (SOEC):

  SOFC/SOEC sealing materials are specially formulated glasses and glass-ceramics that withstand the harsh environments of SOFCs.

  Besides providing hermetic joints, the sealing material also serves as electrical insulation at operating temperatures. Moreover, they feature chemical stability under reducing and oxidizing atmospheres and have a matched coefficient of thermal expansion (CTE) to prevent material stress within the structure. The glass can be applied as dispensable/screen printable glass paste to the interconnects.






Application example: Solid oxide fuel cell

**SCHOTT high temperature glasses overview:**

- Broad portfolio with a wide range of sealing temperatures, maximum operation temperatures and coefficient of thermal expansion available
- Sealants are available in powder form. Pastes, sheets and preforms are customized products and only available upon request.

| SCHOTT glass number | $\alpha_{(20-300)}$ ($10^{-6}$/K) glassy/cryst. | $T_g$ (°C) | Sealing temperature (°C) | Dilatometric Softening Point (°C)[1] | Maximum Operating temperature (°C) | Sealing partner |
|---|---|---|---|---|---|---|
| 8253 | 4.6/-.- | 785 | 1320 | 873 | 735 | SiC |
| G018-200 | 4.6/-.- | 557 | 665 | 612 | 550 | AlN |
| G018-281 | 4.6/12.1 | 639 | 1000 | >850 | 850 | CFY, ScSZ/$ZrO_2$, * |
| G018-266 | 6.9/-.- | 585 | 770 | 640 | 530 | $Al_2O_3$ |
| G018-385 | 8.4/8.4 | 992 | 950 | -.- | 950 | $Al_2O_3$, CFY ScSZ/$ZrO_2$, * |
| G018-358 | 8.5/8.8 | 658 | 940 | -.- | 1040 | $Al_2O_3$, * |
| G018-394 | 8.7 | 681 | 900 | 763 | 850 | CFY, * |
| G018-354 | 9.2 | 637 | 850 | 711 | 750 | $ZrO_2$, FFS, * |
| G018-311 | 9.1/9.9 | 612 | 850 | 686 | 880 | $ZrO_2$, FFS, * |
| G018-409 | 9.4 | 696 | 900 | -.- | 850 | FSS, * |
| GM31107 | 9.8/-.- | 543 | 700 | 592 | 650 | $ZrO_2$, FFS, * |
| G018-397 | 9.9 | 642 | 900 | 778 | 850 | $ZrO_2$, FFS, * |
| G018-391 | 9.8 | 636 | 900 | 708 | 800 | $ZrO_2$, FFS, * |
| G018-392 | 10.6 | 590 | 850 | 696 | 800 | $ZrO_2$, FFS, * |

FFS: Ferritic stainless steel  CFY: Cr5FeY (Plansee SE)
[1] after sealing
*Tested especially for SOFC applications

**Table 14.** SCHOTT high temperature sealing glasses

Application of glass in solid oxide fuel cell

## 9.3 Solder glasses

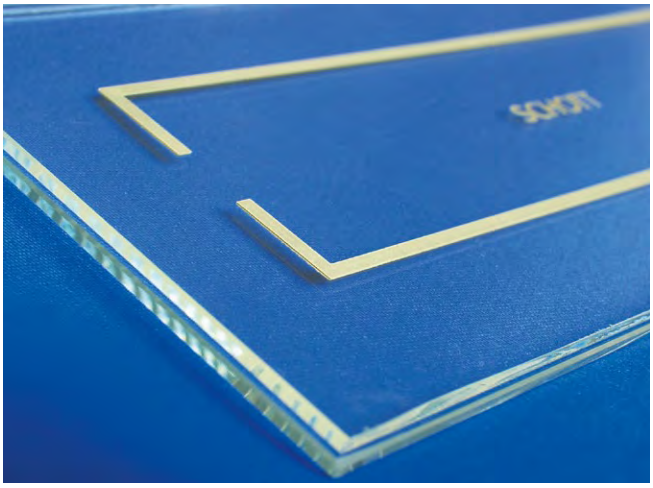
**Solder glasses** are special glasses with a particularly low softening point. They are used to join glass to other glasses, ceramics, or metals without thermally damaging the materials to be joined. Soldering is carried out in the viscosity range $\eta = 10^4 - 10^6$ dPa·s of the solder glass (Figure 41); this usually corresponds to a temperature range $T_{solder} = 350 - 700\,°C$.

We distinguish between vitreous solder glasses and devitrifying solder glasses, according to their behavior during the soldering process.

**Vitreous solder** glasses behave like traditional glasses. Their properties do not change during soldering; upon reheating the solder joint, the temperature dependence of the softening is the same as in the preceding soldering process.

Unlike vitreous solder glasses, **devitrifying solder glasses** have an increased tendency to crystallize. They change into a ceramic-like polycrystalline state during soldering. The viscosity increases by several orders of magnitude during crystallization so that further flowing is suppressed. This time-dependent viscosity behavior is exemplarily shown in Figure 42 for a devitrifying solder glass processed by a specific temperature-time program.

On the other hand, crystallization allows a stronger thermal reload of the solder joint, normally up to the temperature range of the soldering process itself. Devitrifying glasses are available upon request.



Panes of flat glass AF 45 bonded with composite solder glass

The development of solder glasses with very low soldering temperatures is limited by the fact that reducing the temperature generally means increasing the coefficient of thermal expansion. This effect is less pronounced in devitrifying solder glasses. It can be even more effectively avoided by adding inert (non-reacting) fillers with low or negative coefficients of thermal expansion (e.g. $ZrSiO_4$ or β-eucryptite). Such **composite solder glasses** are preferably used to produce stable glass solders.

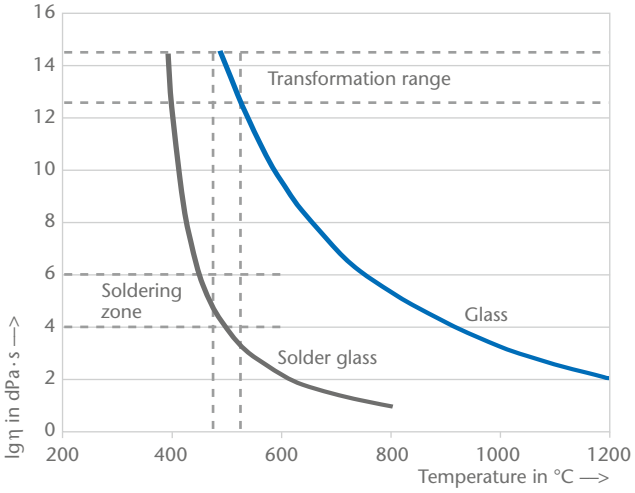



**Fig. 41.** Viscosities η of solder glass to be soldered

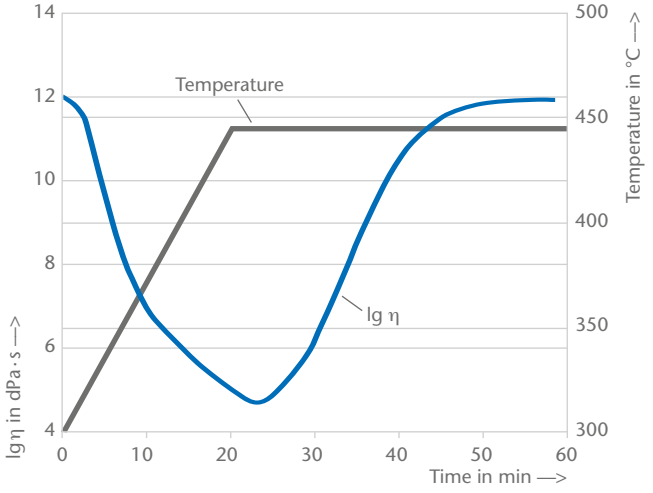



**Fig. 42.** Viscosity development of a crystallizing solder glass during soldering

Because fillers reduce the flow capability during the soldering process, they can be added to the batch only in limited amounts.

Taking into consideration the properties of the materials to be joined, suitable solder glasses are mainly selected under the following aspects:
1. highest permissible soldering temperature,
2. thermal expansion of the materials to be joined,
3. maximum application temperature of the solder zone,
4. chemical behavior.

**Processing**
To achieve satisfactory soldering, the solder glass must flow sufficiently and wet the parts to be joined well. Flow and wetting are temperature- and time-controlled; the higher the temperature, the less time is required for sufficient flow, and vice versa.

Thus, soldering at high temperatures may take only a few minutes, whereas at low temperatures (i.e. at viscosities $\geq 10^7$ dPa·s) reaching sufficient flow takes very long and usually can be achieved only under additional mechanical load.

**Properties**
As with all sealings involving glass, adapting the thermal expansions of the components to be joined with solder glass

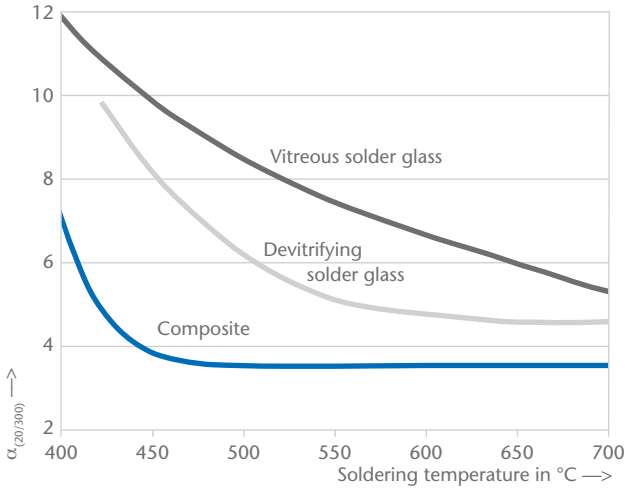



**Fig. 43.** Relationship between soldering temperature and linear expansion α for solder glasses. The curves describe the lowest limits for the respective solder glass types.

Ball lens sealed to a meteal casing with a sintered solder glass ring

is a necessary prerequisite for stable, gas-/leak-tight joins. As a rule, the coefficient of thermal expansion of the solder glasses should be by $\Delta\alpha = 0.5 - 1.0 \times 10^{-6}$/K smaller than the expansion coefficients of the sealing partners.

The relationship between soldering temperature and thermal expansion is schematically shown in Figure 43.

With devitrifying solder glasses, one must consider that the expansion coefficients given in the respective lists of properties are only valid on condition that the specific soldering program defined for each solder glass is complied with. Changing the soldering program, in particular the soldering temperature and the soldering time, may affect the relationship between glassy and crystalline phase and thus change the coefficient of thermal expansion, with the possible result of a mismatch.

Sealing joints produced with vitreous solder glasses can be loaded to approximately 50 K below the transformation temperature of the respective solder glass. The maximum service temperature of devitrifying solder glasses depends on the type and melting point of the precipitated crystals and on the amount and properties of the residual glass phase. Up to maximum service temperature, solder glasses are moisture- and gas-proof. Their good electric insulating property is superior to that of many standard technical glasses. They are therefore also suitable as temperature-resistant insulators. The chemical resistance of solder glasses is generally lower than that of standard technical glasses.

Therefore, solder glass sealings can be exposed to chemically aggressive environments (e.g. acids, alkaline solutions) only for a limited time.

**Deliverable forms and shapes**
Solder glass can be supplied in the form of powder, granulate and sintered preforms (e.g. rings, rods, …), and as paste. An example of a glass-to-metal seal application is shown on page 50, Table 13.

| Glass no. | $\alpha_{(20/300)}$ | $T_g$ | Sealing temperature | | Density |
|---|---|---|---|---|---|
| | | | | $t_{holding}$ | |
| | [$10^{-6}$ x $K^{-1}$] | [°C] | [°C] | [min] | [g/cm³] |
| Lead-containing | | | | | |
| G017-002 | 3.7 | 545 | 700 | 15 | 3.6 |
| G017-339 | 4.7 | 325 | 510 | 15 | 4.3 |
| G017-712 | 5.3 | 375 | 510 | 10 | – |
| G017-393 | 6.5 | 320 | 425 | 15 | 4.8 |
| G017-340 | 7.0 | 315 | 420 | 15 | 4.8 |
| G018-228 | 7.6 | 311 | 400 | 15 | 5.0 |
| 8465 | 8.2 | 385 | 520 | 60 | 5.4 |
| G018-229 | 8.7 | 310 | 410 | 15 | 5.4 |
| G018-256 | 9.6 | 316 | 420 | 15 | 5.8 |
| G017-052 | 11.7 | 308 | 410 | 15 | 6.7 |
| | | | | | |
| Lead-free | | | | | |
| G018-250 | 7.0 | 380 | 510 | 15 | 5.7 |
| G018-255 | 9.4 | 396 | 520 | 15 | 6.7 |
| 8470 | 10.0 | 440 | 680 | 60 | 2.8 |
| G018-423 | 10.0 | 338 | 450 | 15 | 7.2 |
| G018-249 | 10.1 | 365 | 500 | 15 | 7.1 |
| G018-213 | 13.1* | 314 | 500 | 30 | 2.8 |

*CTE 20–250 °C

Other matched CTE available upon customer request
All solder glasses are available as K3 powder. Grain size: $d_{50} = 10 \pm \alpha_{\mu m}$, $d_{99} \leq 63_{\mu m}$

Other grain sizes available upon request

**Table 15.** SCHOTT solder glasses

## 9.4 Passivation glasses

**Passivation glasses** are zinc-borosilicate and lead-alumina silicate glasses used for chemical and mechanical protection of semiconductor surfaces.

**Processing**
To avoid distortion and crack formation, the different coefficients of thermal expansion of the passivation glass and the other semiconductor components must be taken into account. If the mismatch is too large, a network of cracks will originate in the glass layer during cooling or subsequent processing and destroy the hermetic protection of the semiconductor surfaces. Basically, there are three ways of overcoming this problem:

The thinner the passivation glass layer, the smaller is the risk of cracking. SCHOTT therefore recommends maximum thicknesses for all homogeneous passivation layers that, as a rule, should not be exceeded.

The sealing stress between glass and silicon, and thus the risk of cracking, can be reduced by slow cooling in the transformation range. As a rough rule, a cooling rate of 5 K/min is suitable for passivation layers in the temperature range $T_g \pm 50$ K.

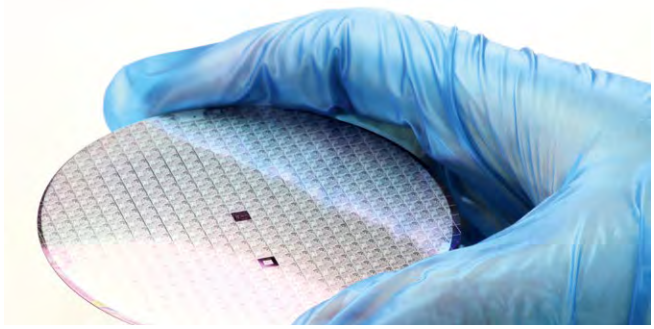
Another way of avoiding thermal expansion mismatches is using composite glasses. Composites consist of a mixture of passivation glass powder and an inert filler such as, for example, powdered ceramics with very low or negative thermal expansion. Such fillers lower the mean thermal expansion coefficient of the passivation glass and thus minimize or eliminate the risk of cracking. As a secondary effect, fillers improve the mechanical stability of the composite glass.

Different processing techniques, adjusted to the requirements of the respective applications, are employed. For the manufacturing of sintered glass diodes, usually a slurry of glass powder and deionized water is applied to the diode body, including the Mo- or W-contact studs. For wafer passivation (glass applied to the Si wafer before separating the chips), an organic suspension is applied by spinning, doctor blading, sedimentation, electrophoresis, or screen printing. The organic suspension vehicles must be completely volatile or thermally decomposable below the softening temperature of the glass.

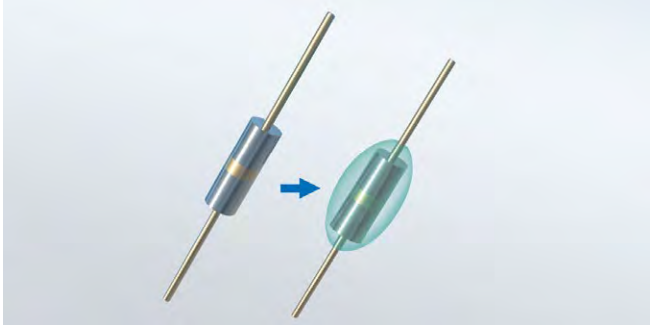
**Properties**
Electrical insulation, including dielectric breakdown resistance, generally depends on the alkali content, particularly on the $Na^+$ content. Alkali contamination in SCHOTT passivation glasses is kept low by selecting pure raw materials and special manufacturing procedures. Contamination is tested for every batch. Typical contents are below 100 ppm for $Na_2O$ and $K_2O$, and below 20 ppm for $Li_2O$. Some composite passivation glasses may contain fillers with slightly higher amounts of alkali; because the mobility of alkali ions is negligible, there is no risk of impairing the quality of the component.

Heavy metals which are incompatible with semiconductors are controlled as well. The CuO content, for example, is below 10 ppm.

Because the mobility of charge carriers increases drastically with increasing temperature, a temperature limit, called junction temperature $T_j$, is defined up to which glass-passivated components can be used in blocking operations.



Passivation glasses enable chemical and mechanical strengthening of semiconductor and varistor surfaces



Glass powders are used to passivate and encapsulate sinter glass diodes and glass bead rectifier diodes

| Lead-containing | Type | Main applications | $\alpha_{(20/300)}$ $10^{-6}$/K | $T_g$ °C | Pb contents wt% | Firing temp. °C | Holding time min. | $T_j$ °C |
|---|---|---|---|---|---|---|---|---|
| G018-205 | Pb-Zn-B | sinter glass diodes | 4.45 | 541 | 1–5 | 690 | 10 | – |
| G017-388 | Zn-B-Si composite | thyristors, high-blocking rectifiers | 3.6 | 550 | 1–5 | 700 | 5 | 180 |
| G017-002 | Zn-B-Si composite | sintered glass diodes | 3.7 | 545 | 1–5 | 700 | 10 | 180 |
| G017-096R | Pb-B-Si | sinter glass, planar- and mesa-diodes | 4.8 | 456 | 10–50 | 680 | 5 | 160 |
| G017-004 | Pb-B-Si composite | mesa diodes | 4.1 | 440 | 10–50 | 740 | 5 | 160 |
| G017-230 | Pb-B-Si composite | transistors | 4.2 | 440 | 10–50 | 700 | 4 | 160 |
| G017-725 | Pb-B-Si | sinter glass diodes | 4.9 | 468 | 10–50 | 670 | 10 | 180 |
| G017-997 | Pb-B-Si composite | wafer passivation | 4.4 | 485 | 10–50 | 760 | 20 | 180 |
| G018-133 | Pb-B-Si composite | sinter glass diodes | 4.8 | 463 | 10–50 | 690 | 30 | – |
| | | | | | | | | |
| Lead-free | | | | | | | | |
| G018-434 | Zn-B-Si | wafer passivation | 4.1 | 563 | 0 | 675 | – | – |
| G018-255 | Bi-Zn-B | varistors | 9.4 | 396 | 0 | 520 | 15 | – |

**Table 16.** SCHOTT passivation glasses

In manufacturing, glass passivation is often followed by chemical processes (such as etching of contact windows or electrolytic deposition of contacts) which may attack the glass. The chemical resistance of the various passivation glasses differs strongly and is an important criteria in selecting the appropriate glass type and etching process.

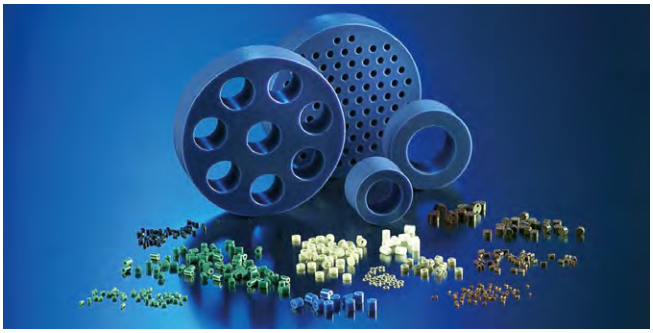
**Forms of supply**
Passivation glasses are supplied as glass powders, ground iron-free and with negligible abrasion. Passivation glasses are available as tubing or sleeves for use in certain applications. They are available in various grain sizes (generally type K, see Table 16) to suit the respective application.

## 9.5 Deliverable forms of supply

Most glasses for joining can be supplied in the form of powders, preforms and as paste. The glasses are generally available as K3 powder, with a mean grain size $d_{50}$ = 10 ± 2 µm and $d_{99} \leq 63$ µm. Other grain sizes are available upon request.

Variously shaped preforms are pressed from granulated glass powder, which is bonded by an organic binder. During the subsequent thermal process, the binder is removed and the glass particles sinter. Such sintered preforms are typically used in glass-to-metal seals, where exemplary applications are shown on page 49.

Glass pastes typically consist of glass powders, organic binder and a solvent. They possess a defined viscosity in order to be screen-printed or dispensed for sealing purposes.



Sintered preforms are available in customized geometries from millimeter to centimeter range.

# 10. Porous glasses

## 10.1 Introduction to porous glasses

Porous glasses have attracted great interest in recent years, as they help to improve accuracy and efficiency of pharmaceutical, chemical and biological applications. They also enable entirely new processes and functionalities in a broad variety of other applications.

Their interconnected and controlled porosity and the possibility to perform microstructure modelling enable easy functionalization of porous glasses.

Usage examples include filtering/purification, size exclusions, and chromatographic separation of enzymes, bacteria and proteins, Furthermore, the large internal surface of porous glass allows its use in desiccation processes, yet also provides a high binding capacity. This enables its use as a carrier for liquids and other active substance. Some application examples are shown in the graphic below.

In comparison to other porous materials, key advantages of porous glasses are found in its high chemical, thermal, and mechanical resistance that give it an extremely rigid and incompressible structure. They are available as ultra-fine glass powders and granulates, or as larger user-defined pieces. These include forms such as blocks, rods, and complex shapes/textures.

SCHOTT offers two high-quality porous glass types for the nanometer- or the micrometer-range. SCHOTT CoralPor® starts from approximately 4 nm pore size. SCHOTT Macroporous glass starts from 10 µm pore size and upwards to any desired value.

## 10.2 SCHOTT CoralPor® Nanoporous Glass

**Description**
Under a scanning electron microscope, CoralPor® porous glasses resemble the structure of its namesake coral skeletons. At high magnification, countless pores and channels are revealed. The interconnected coral-like structure is created during a special production process in which borosilicate mother glass is subjected to meticulously controlled thermal and chemical treatments. This creates open porosity that can be tailored to meet even the most demanding customer specifications.

**Product attributes**
Our innovative nanoporous material is currently available in two product variants:

- CoralPor® 1000 is the ideal choice for ultra-nanoporous applications up to 10 nm
- CoralPor® 2000 offers pore sizes up to 300 nm

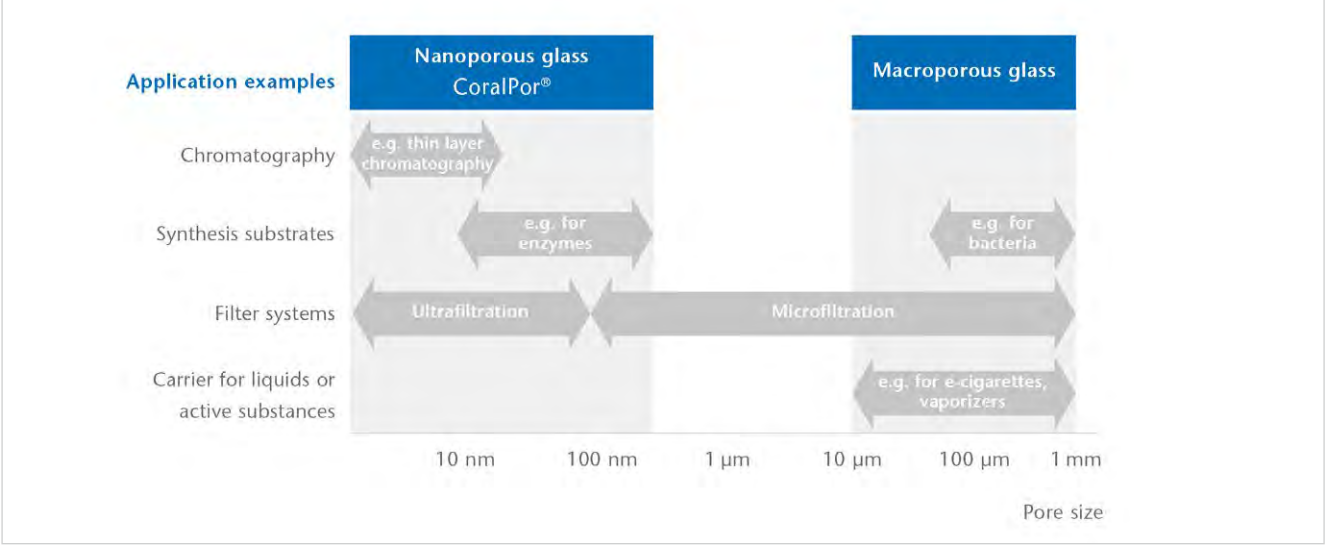



**Fig. 44.** Application examples for nanoporous and macroporous glass

| | CoralPor® 1000 | CoralPor® 2000 |
|---|---|---|
| Average pore diameter | 4–10 nm | 20–300 nm |
| Pore diameter distribution | 10–30% | 7–25% |
| Surface area | 100–170 $m^2/g$ | 7–100 $m^2/g$ |
| Pore volume | 0,2–0,3 $cm^3/g$ | 0,4–1,0 $cm^3/g$ |
| Typical applications | – Medical devices<br>– Desiccants<br>– High temperature applications<br>– Coatings<br>– Reference electrode junction<br>– 3D-printers | – Filter systems<br>– Chromatography<br>– Synthesis substrate/ Catalyst support |
| Products | Powder/monoliths | |

**Table 17.** Technical properties of CoralPor® 1000 and CoralPor® 2000

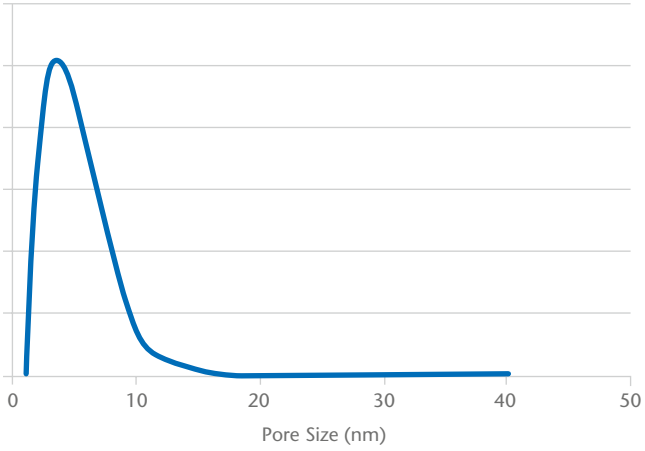



**Fig. 45.** CoralPor® 1000

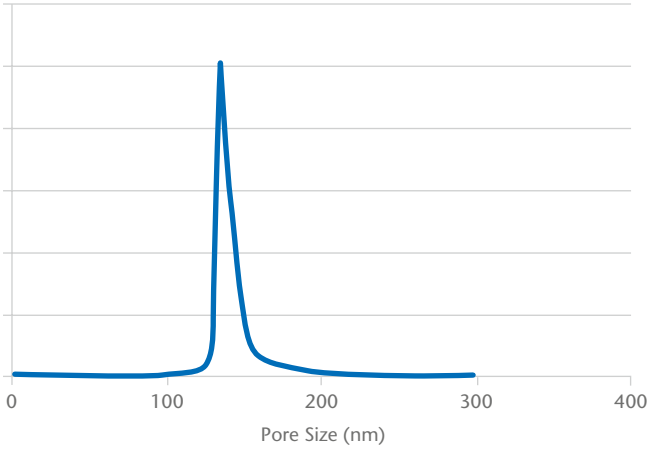
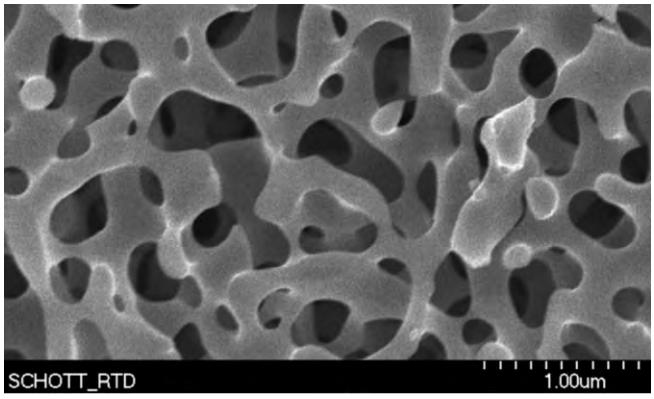



**Fig. 46.** CoralPor® 2000

### Advantages

- Excellent absorption and separation capabilities due to very large internal surface area and narrow pore size distribution
- Enabling stable results and efficiency due to ultra-robust, long-lasting material:
  – Low coefficient of thermal expansion
  – High thermal stability
  – High chemical resistance against a large variety of different media




Cold field emission scanning electron microscope image of SCHOTT CoralPor® porous glass

## 10.3 SCHOTT Macroporous Glass

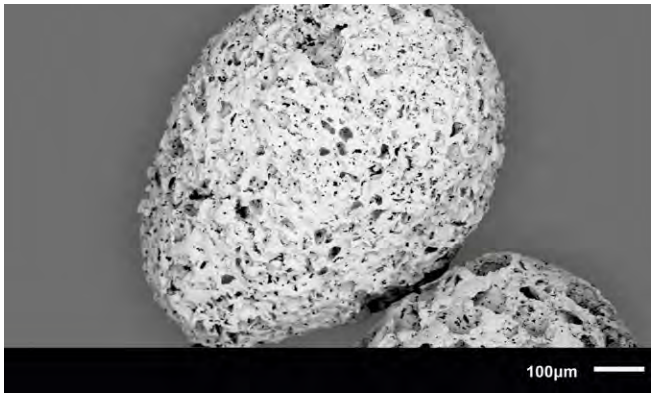
**Description**
SCHOTT also provides material with coarser pore structure. Those materials usually consist of alkali silicate or borosilicate glasses but are not limited to such compositions. The open porous structure can tailored over a wide range of size and volume.

**Product attributes**
- Average pore size adjustable: 10–1000 µm
- Pore volume up to 80 %

**Advantages**
- High specific surface area
- Excellent thermal stability depending on base glass
- Completely inorganic
- Customized surface treatment upon demand

**Products**
- Sintered components in various shapes and sizes
- Porous microspheres

**Applications**
- Storage device for liquids
- Evaporation units
- Carrier/Substrate for active substances
- Filters




SEM-image of SCHOTT Macroporous Glass

Sintered Macroporous glass is available in various shapes and sizes

# 11. Glass-Ceramics for Industrial Applications and Home Appliances

## 11.1 Introduction to glass-ceramics

Glass-ceramics are distinguished from glass and ceramics by their characteristic manufacturing process (see Figure 47) and by their properties. Not classifiable as glass or as ceramic, they represent a completely new class of materials.

They are manufactured in two principal production steps. In the first step, a batch of exactly defined composition is melted (as for normal glass). The composition is determined by the desired properties of the end-product as well as by the necessary working properties of the glass. After melting, shapes are produced by pressing, blowing, rolling or casting and then annealed. In this state, the material still exhibits all the typical characteristics of glass.

In the second step, the "glassy" articles are subjected to a specific temperature-time treatment between 800–1200 °C (defined for each composition), by which they are ceramized, i.e. they are transformed into a mainly polycrystalline material. Apart from the crystalline phase with crystals of 0.05–5 µm in size, this material contains a residual glass phase of 5–50 %.

In the temperature range between 600–700 °C, small amounts of nucleating agents (e.g. $TiO_2$, $ZrO_2$ or F) induce precipitation of crystal nuclei. As the temperature increases, crystals grow on these nuclei. Their type and properties as well as their number and size are predetermined by the glass composition and the annealing program. By appropriate program selection, either transparent, slightly opaque, or highly opaque, non-transparent glass-ceramics can be produced. Unlike conventional ceramics, these glass-ceramics are absolutely dense and pore-free. To achieve controlled

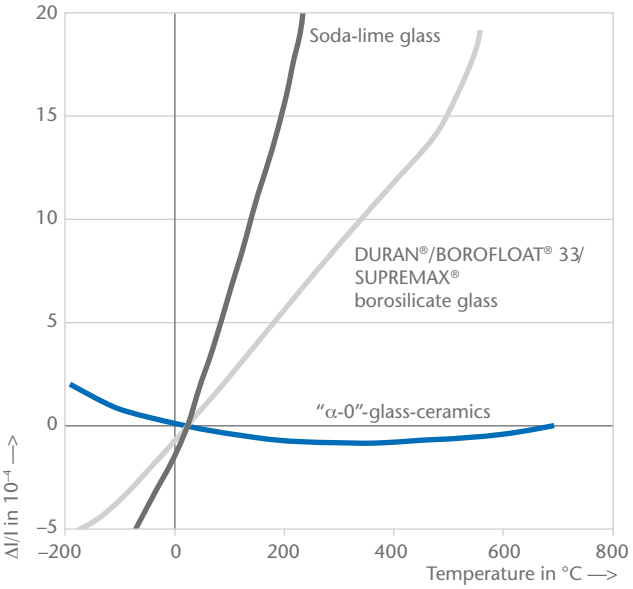



**Fig. 48.** Thermal expansion of "α-0"-glass-ceramics compared to borosilicate glass 3.3 and soda-lime glass

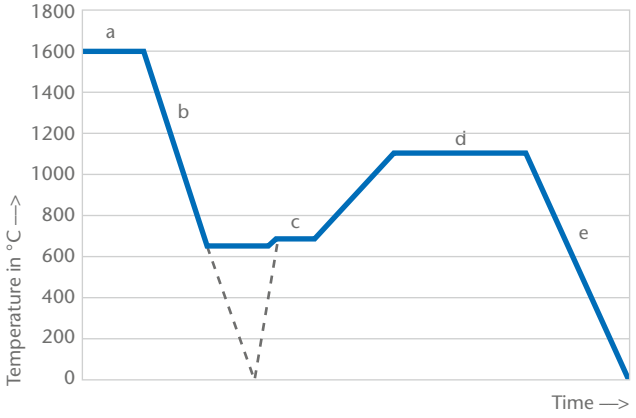



**Fig. 47.** Temperature-time schedule for glass-ceramic production
a: melting, b: working, c: nucleation, d: crystallization,
e: cooling to room temperature

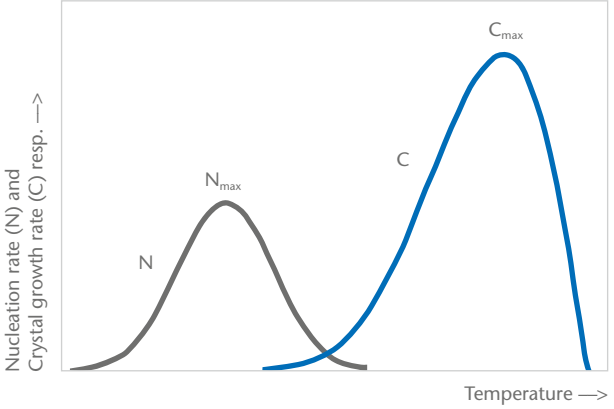



**Fig. 49.** Nucleation rate (N) and crystal growth rate (C) of glasses, related to temperature

crystallization in the glass, the temperature difference between the nuclei formation region and the crystal growth region must be sufficiently large (Figure 49). In this way, spontaneous crystallization during hot forming and unwanted crystal growth during nucleation can be avoided.

Like the glass composition, the composition of glass-ceramics is highly variable. Well-known compositions lie within the following systems:
$Li_2O–Al_2O_3–SiO_2$; $MgO–Al_2O_3–SiO_2$; $CaO–P_2O_5–Al_2O_3–SiO_2$.

Glass-ceramics of the $Li_2O–Al_2O_3–SiO_2$ system that contain small amounts of alkali and alkaline earth oxides as well as $TiO_2$ and $ZrO_2$ as nucleating agents have achieved great commercial significance. Based on this system, glass-ceramics with coefficients of linear thermal expansion of close to zero can be produced (Figure 48 and Table 18). This exceptional property results from the combination of crystalline constituents (such as solid solutions of h-quartz, h-eucryptite or h-spodumene), with negative coefficients of thermal expansion, and the residual glass phase of the system, with a positive coefficient of thermal expansion.

Such "α-0"-glass-ceramics can be subjected to virtually any thermal shock or temperature variation below 700 °C, whereby wall thickness, wall thickness differences, and complicated shapes are of no significance.

Another technical advantage is the exceptionally high dimensional and shape stability of objects made from these materials, even when subjected to considerable temperature variations.

An application for CERAN® glass-ceramic cooktop panels: e.g. SCHOTT CERAN® for induction

## 11.2 PYRAN® Platinum

PYRAN® Platinum is the world's first fire-rated glass-ceramic manufactured using the microfloat process. It offers an outstanding surface quality and unprecedented color neutrality.

PYRAN® Platinum is the only environmentally-friendly fire-rated glass-ceramic produced without the hazardous heavy metals antimony and arsenic. It is UL (Underwriters Laboratories) classified for fire-ratings up to 180 minutes and passes the required hose stream test. PYRAN® Platinum fire-rated glass-ceramic is intended for use in non-impact, safety-rated locations such as transoms and windows. The filmed and laminated PYRAN® Platinum glass-ceramic products are impact safety-rated and meet the requirements according to ANSI (Cat. I and II). They are intended for use in safety-rated locations such as door lites, transoms or sidelites, and windows.

| | Unit | Product class | ZERODUR® | Glass-ceramics for cooktop panels |
|---|---|---|---|---|
| $\alpha_{0/50}$ | $10^{-6}$/K | Extreme<br>Special<br>Exp Cl 0<br>Exp Cl 1<br>Exp Cl 2 | 0 ± 0.007<br>0 ± 0.010<br>0 ± 0.02<br>0 ± 0.05<br>0 ± 0.1 | |
| $\alpha_{20/300}$<br>$\alpha_{20/500}$<br>$\alpha_{20/600}$<br>$\alpha_{20/700}$ | $10^{-6}$/K<br>$10^{-6}$/K<br>$10^{-6}$/K<br>$10^{-6}$/K | | +0.1<br>–<br>+0.2<br>– | –0.2<br>–0.01<br>–<br>+0.15 |
| Density<br>Young's modulus E<br>Poisson's ratio μ | g/cm³<br>GPa | | 2.53<br>90<br><br>0.24 | 2.56<br>92<br><br>0.24 |

**Table 18.** Coefficient of linear thermal expansion α, density and elastic properties of ZERODUR® and glass-ceramics for cooktop panels

## 11.3 ZERODUR®

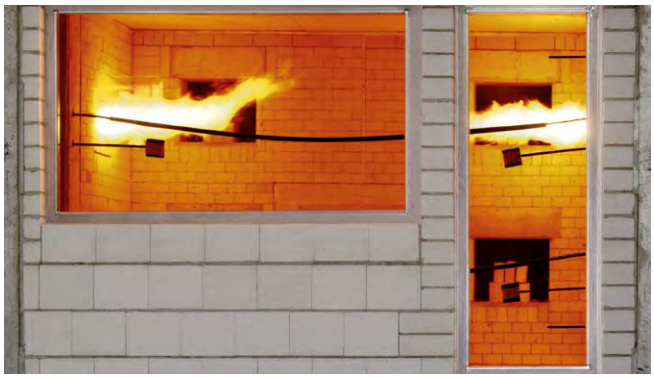
ZERODUR® glass-ceramic whose coefficient of linear thermal expansion at room temperature can be kept as low as $\leq \pm 0.007 \times 10^{-6}$/K (Table 18) was originally developed for the production of large mirror substrates for astronomical telescopes. Today ZERODUR® is used in components for applications, which require the tightest control of dimensions under temperature variation such as IC and LCD lithography, precision measurement and navigation of airplanes and submarines.

To meet the highest precision requirements the production of ZERODUR® TAILORED can be adapted to achieve minimal thermal expansion at customer application temperature conditions.

Next to the extremely low values of thermal expansion, the homogeneity of this property is of crucial importance for IC lithography components. ZERODUR® blanks up to 4 m in size are frequently produced with CTE homogeneity values in the range of several parts per billions per degree K.

## 11.4 NEXTREMA®

Besides the well-known glass-ceramic products ROBAX® for fireplaces and CERAN® for cooktop applications, SCHOTT has developed and introduced the glass-ceramic material platform NEXTREMA®. NEXTREMA® glass-ceramic panels are recommended for use in technical applications. NEXTREMA® demonstrates what makes glass-ceramic a ground-breaking and unique solution, particularly in high temperature environments.



PYRAN® Platinum fire-rated glass-ceramic product lines pass the fire and hose stream tests.

1.2-m light-weight mirror substrate, polished, ZERODUR® glass-ceramic

The material is manufactured e.g. in sheet form and can be further processed by using a wide variety of technologies. The following different features are in principal producible – all others upon request:

- Flat random sheets
- Flat cut-to-size panels
- Bent panels
- Different surface structures, e.g. smooth, nubby or grooved

NEXTREMA® is a type of glass-ceramic consisting of a crystalline and a residual glassy phase. The glass is obtained e.g. by a rolling process and is subsequently subjected to a heat treatment as described in the introduction before. This is called ceramization which transforms, in a controlled manner, the glass almost completely into both a fine grained crystalline phase and a residual glassy phase. Mainly different ceramization processes determine both the features and the types of NEXTREMA® available. The approach is to design glass-ceramic that corresponds to the individual and specific requirements as precisely as possible. Each product feature individually or particularly combined can lead to new technical developments and fields of application.

The glass-ceramic is available in 6 different types:

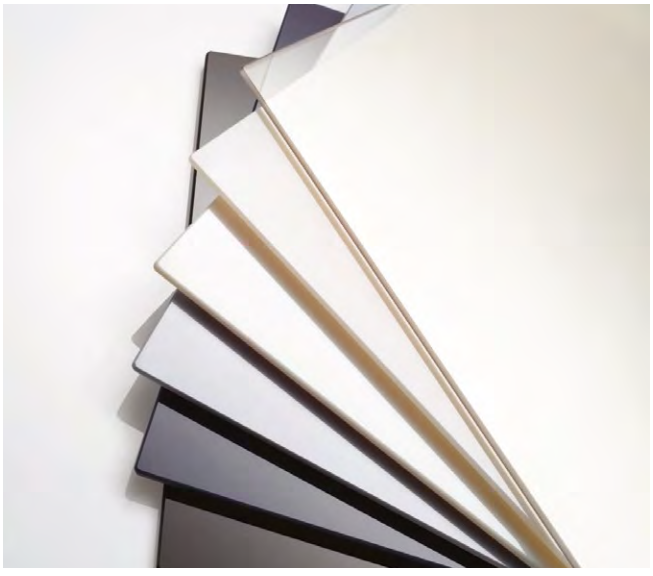
I. transparent (724-3)
II. translucent white (724-5)
III. opaque white (724-8)
IV. tinted (712-3)
V. translucent bluegrey (712-6)
VI. opaque grey (712-8)

With NEXTREMA® we offer engineers and designers alike a unique and homogeneously colored glass-ceramic material platform. All six types have the following material benefits in common, however, slightly varying depending on the type.

1. Robustness at high operating temperatures (up to 950 °C/1742 °F).
2. Near zero thermal expansion and excellent thermal strength due to its microstructure.
3. Thermal shock resistance up to 820 °C/1508 °F and withstanding relatively fast temperature changes.
4. Wide transmittance spectrum in visible light and infrared range. Furthermore, all NEXTREMA® types are UV blocking.
5. Surface resistance and gas impermeability – chemically resistant to acids, bases and corrosion-resistant special glass according to DIN 12116, ISO 695, and DIN ISO 719.
6. NEXTREMA® is practically process inert and even under extreme conditions the material will not have negative interactions with the process environment. There are no interfering process factors such as gas emissions from organic components.

The combination of these outstanding technical properties enable the usage for a wide range of technical appliactions, e.g.

- Solar processing
- LCD/AMOLED processing
- Heating/Lighting (e.g sauna, space heating, IR-heating/drying)
- Food processing (e.g. grills, toasters, microwave applications)
- Setters for firing electronic components
- Carrier plates in CVD-furnaces
- Cover panels for heating elements and burners
- Cover panels for projectors/beamers/photocopiers
- Windows for combustion furnaces
- Carrier/protection plates for food processing industries
- Linings for furnaces
- Glass-ceramic carrier plates for sputtering



NEXTREMA® high-performance glass-ceramic

# 12 Optical Materials

## 12.1 Introduction of Advanced Optics

**SCHOTT Advanced Optics – Your Partner for Excellence in Optics.**
Today, the Advanced Optics unit of SCHOTT offers optical materials, components and filters and has been a trailblazer for various applications.

With a product portfolio of over 120 optical glasses, special materials (e.g. active laser glass, IR-Materials, sapphire), ultra-thin glass, high-precision optical components, wafers, and optical filter glasses, Advanced Optics develops customized solutions all over the world for applications in optics, lithography, astronomy, opto-electronics, life sciences, research, Machine Vision, and more.

Advanced Optics masters the entire value chain: from customer-specific glass development and its melting all the way to high-precision optical product finishing, processing and measurement.

**For more information on Advanced Optics, visit our website: www.schott.com/advanced_optics**

## 12.2 Product overview

**Optical Glass – More than 120 high-quality optical glasses**
For more than 130 years, SCHOTT has been offering a large portfolio of high-quality optical glasses to meet the needs of a broad variety of optical applications as well as industrial applications, ranging from consumer products to optical systems at the leading edge of research.

Our range of optical glasses includes environment-friendly N-glasses, glasses suitable for precision molding (low Tg-Glass) as well as classical glass types with lead oxide as an essential component for outstanding optical properties. In addition, we offer special versions of our glasses, e.g. high transmission glasses (HT- & HTultra-Glasses) or our high homogeneous glasses as well as the tightest tolerances available on market.

**Optical filter glass**
Filter glasses enable applications in analytics, photography, medical technology and laser protection. Optical filter glass is known for its selective absorption in the visible wavelength range. The optical filter glasses appear to be colored if their filter effect lies within the visible light spectrum.

SCHOTT's optical filter glasses include the following filter types in the wavelength range above 200 nm:
- Bandpass filters
- Longpass filters
- Shortpass filters
- Neutral density filters
- Contrast enhancement filters
- Multiband filters and
- Photo filters

**Interference filters**
Interference filters that use the interference effect to obtain spectral transmission are manufactured by depositing thin layers with different refractive indices onto a substrate. These filters are used for applications in medical technology, for analytics in measurements, environmental, biotech, chemical and medical, fluorescence microsopy, and more fields.

SCHOTT supplies standard and customized interference filters within the spectral range of 200 nm to 3,000 nm.

Our product range comprises various types of interference filters:
- Bandpass filters
- Edge filters
- Notch filters
- DUG 11
- Hard bandpass filters
- i-line filters
- VERIL linear variable filters
- Hard (scratch-resistant) and broadband AR coated
- Beamsplitters
- Neutral density filters
- Mirror coatings
- Black coatings

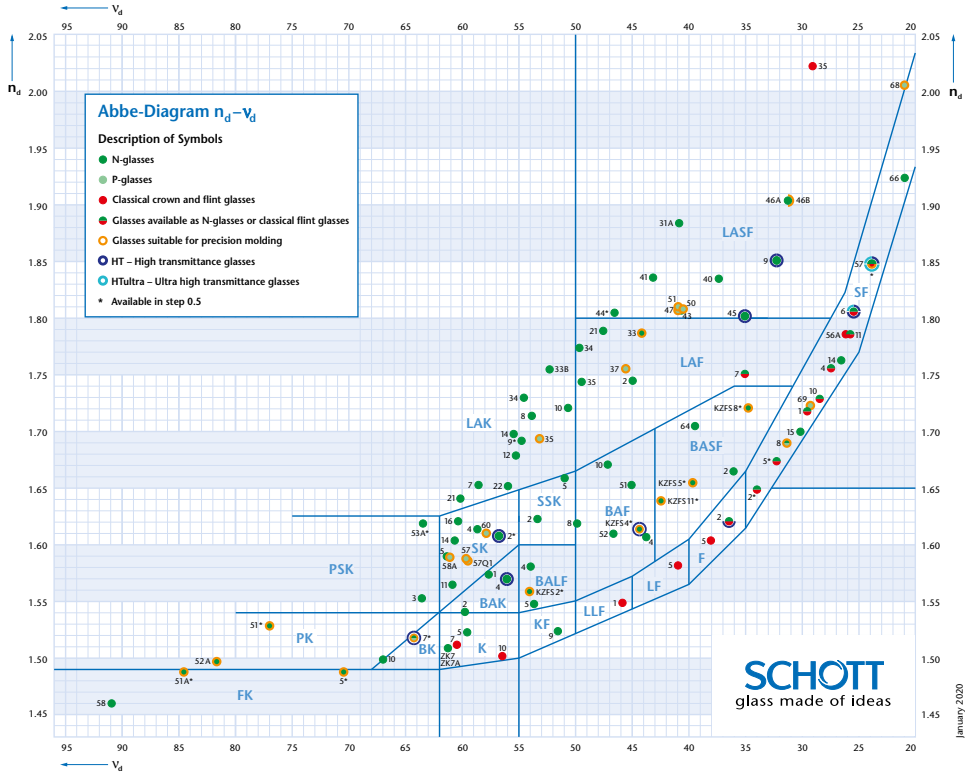



**Fig. 50.** Abbe Diagram

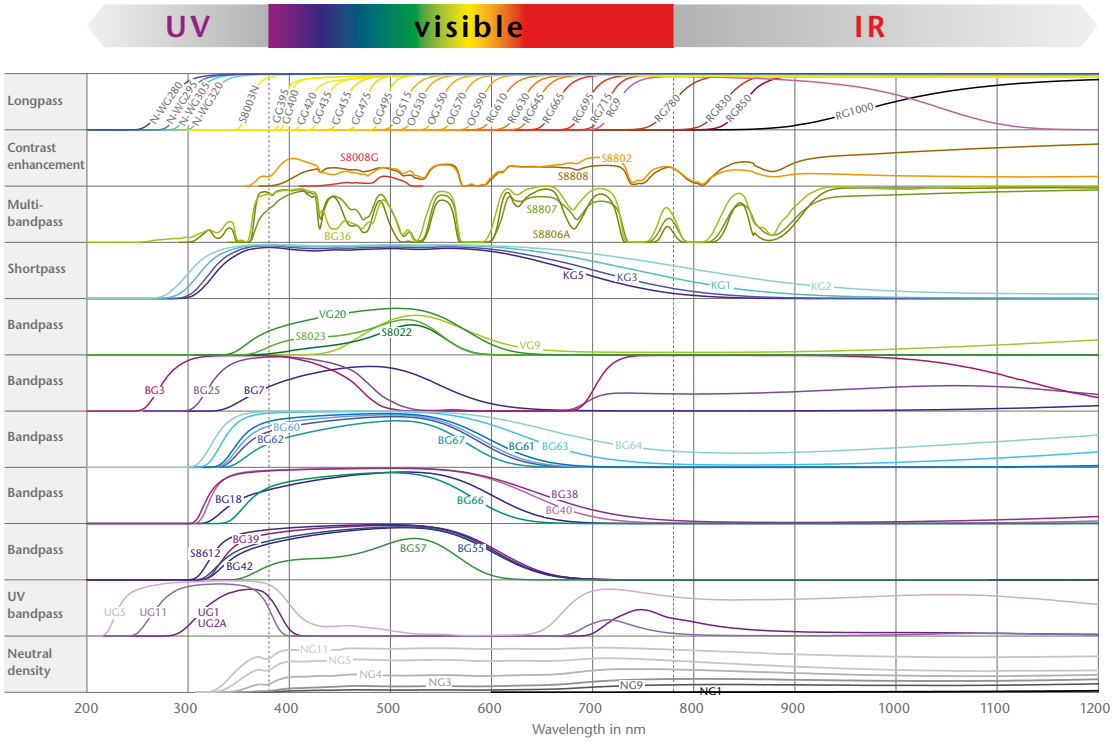
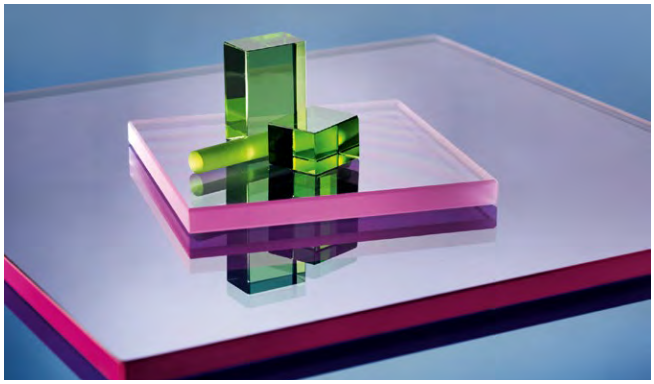
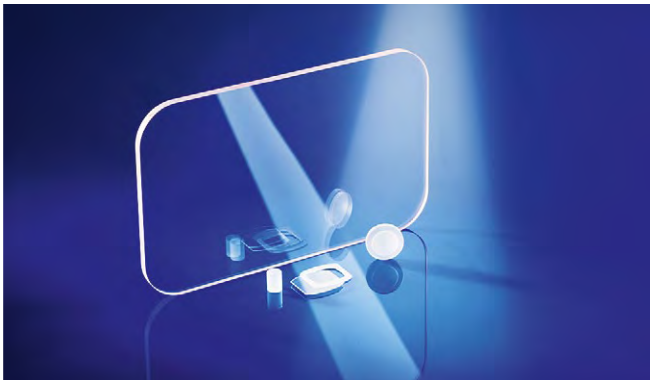



**Fig. 51.** Internal transmittance of SCHOTT filter glasses



Laser glass



Sapphire

**Active and passive laser glass**
SCHOTT offers active & passive laser glasses from neodymium-doped laser glasses and special filter glasses for use as active laser medium and diagnostic filters to ultra-stable glass-ceramic for laser applications requiring the utmost precision.

**Infrared chalcogenide glass**
Infrared glasses offer excellent transmission in the shortwave, midwave, and longwave IR-range. These glasses encompass the common IR transmission bands 3–5 µm and 8–12 µm, but can transmit as low as 0.7 µm. These glasses are used for night vision systems, thermal cameras, in medical applications, and much more.

**Sapphire**
Sapphire offers a broad transmission range from UV to mid-infrared wavelengths (250–5,000 nm). This material is capable of withstanding extreme environmental conditions and fluctuations in temperature. SCHOTT offers sapphire in processed shapes according to the customer's specifications.

**i-line glass**
i-line glasses are optical glass types named after the i-wavelength that offer both high UV-transmittance at 365 nm and high refractive index homogeneity. These glass types can be found in lithography applications such as i-line steppers and wafer scanners.

Infrared chalcogenide glass

i-line glass

Ceramic Laser Phosphor Converter

ZnS FLIR

**Ceramic Laser Phosphor Converter**
Ceramic Laser Phosphor Converter is an inorganic phosphor material. The raw material is produced in Mainz, post processing is done in Malaysia.

Products offered: Phosphor rings and phosphor dies on heatsinks for digital projection and specialty lighting such as spotlights and search lights.

Ceramic Laser Phosphor Converters are used for laser pumped phosphor light sources for high brightness digital projectors and also for special laser based lighting solutions, that require superior luminence.

**Zinc Sulfide ZnS CLEAR**
Polycrystalline Zinc Sulfide (FLIR – Forward Looking Infrared) is manufactured through applying a chemical vapor deposition (CVD) process. To produce ZnS CLEAR, ZnS FLIR is treated using a hot isostatic pressing process to eliminate microscopic voids and defects that occur in the regular grade-material.

ZnS CLEAR is commonly used in multispectral applications across the visible to infrared region from 0.4 µm – 12 µm. It is available in large sizes and custom shapes and formats. These can include windows, domes or lens blanks.

**Zinc Sulfide ZnS FLIR**
Regular (FLIR) grade ZnS is a polycrystalline optical material that offers high performance in terms of fracture strength and hardness. ZnS FLIR is often used in the 8–12 µm region. The material is used in applications such as IR windows for military systems.

# Glass Types

The information contained in this brochure was updated in 2014.

| | |
|---|---|
| 8095 | Lead glass (28 % PbO), electrically highly insulating, for general electro-technical applications |
| 8100 | Lead glass (33.5 % PbO), electrically highly insulating highly X-ray-absorbing |
| 8228 | Intermediate sealing glass |
| 8229 | Intermediate sealing glass |
| 8230 | Intermediate sealing glass |
| 8240 | Alkaline earth aluminosilicate glass for high temperature application in electrical engineering, for sealing to molybdenum, free from alkali, blue colored, defined absorption |
| 8241 | Alkaline earth aluminosilicate glass for high temperature application in electrical engineering, for sealing to molybdenum, free from alkali, blue colored, defined absorption |
| 8242 | Borosilicate glass for Fe-Ni-Co-alloys and molybdenum, electrically highly insulating |
| 8245 | Sealing glass for Fe-Ni-Co alloys and molybdenum, minimum X-ray absorption, chemically highly resistant |
| 8250 | Sealing glass for Fe-Ni-Co alloys and molybdenum, electrically highly insulating |
| 8252 | Alkaline earth aluminosilicate glass for high temperature applications, for sealing to molybdenum |
| 8253 | Alkaline earth aluminosilicate glass for higher temperature applications, for sealing to molybdenum |
| NEO 1730 | Alkaline earth, Neodymium containing, violet color aluminosilicate glass for high temperature applications in electrical engineering, for sealing to molybdenum, free from alkali |
| 8270 | Borosilicate glass for sealing to KOVAR metal and molybdenum, electrically highly insulating, defined UV absorption, stabilized against solarization |
| 8326 | SBW glass, neutral glass tubing, chemically highly resistant |
| 8330 | DURAN®/BOROFLOAT® 33 and SUPREMAX® borosilicate glass, all-purpose glass mainly for technical applications such as apparatus for the chemical industry, pipelines and laboratories |
| 8337B | Borosilicate glass, highly UV-transmitting, for sealing to glasses and metals of the Kovar / Vacon-10/11 range and Tungsten |
| 8341 | BOROFLOAT® 40, borosilicate floatglass adapted for thermal tougthening |
| 8347 | Colorless, highly transmitting 8330 |
| 8350 | AR-GLAS®, soda-lime silicate glass |
| 8360 | Soft glass, lead-free |
| 8366 | Glass suitable for bodies of glass electrodes |
| 8405 | Highly UV-transmitting soft glass |
| 8412 | FIOLAX® clear, neutral glass, chemically highly resistant, for pharmaceutical packaging |
| 8414 | FIOLAX® amber, neutral glass, chemically highly resistant, for pharmaceutical packaging |
| 8415 | ILLAX®, amber glass for pharmaceutical packaging |
| 8436 | Glass, particularly resistant to sodium vapors and alkaline solutions, suitable for sealing to sapphire |
| 8447 | Intermediate sealing glass |
| 8448 | Intermediate sealing glass |
| 8449 | Intermediate sealing glass |
| 8450 | Intermediate sealing glass |
| 8465 | Low melting lead-alumino-borosilicate solder glass. Good match to materials with thermal expansion of 8.5 … 9.5 ppm/K. |
| 8470 | Lead-free borosilicate solder glass for sealing of materials with thermal expansion of 10.5 … 11.5 ppm/K |
| 8487 | Sealing glass for Tungsten |
| 8488 | SUPRAX®, borosilicate glass, chemically and thermally resistant |
| 8516 | IR-absorbing sealing glass for Fe-Ni, lead-free, low-evaporating |
| 8531 | Soft glass, sodium-free, high lead content, for encapsulation of semiconductor components at low temperatures (diodes) |
| 8532 | Soft glass, sodium-free, highly lead-containing, for encapsulation of semiconductor components at low temperatures (diodes) |
| 8625 | IR-absorbing biocompatible glass for (implantable) transponders |
| 8650 | Na- and K-free sealing glass for molybdenum, especially for implosion diodes, highly lead-containing, passivation glass |
| 8651 | Tungsten sealing glass for power and PIN diodes, passivation glass |
| 8652 | Tungsten sealing glass for power and PIN diodes, low melting passivation glass |
| 8660 | Borosilicate glass for sealing to Tungsten of high cesium content |

| | |
|---|---|
| 8689 | Borosilicate glass, highly UV-blocked, stabilized against solarization, sealing glass to Tungsten |
| 8708 | PYRAN® Platinum, transparent floated glass-ceramic |
| 8800R | Neutral glass, highly chemical resistant |
| AF32 eco | Alkaline free alumino silicate glass |
| Borofloat | Borosilicate glass |
| B270®i | High purity soda lime glass |
| D263T eco | Clear borosilicate glass |
| G017-002* | Composite passivation glass, consisting of zinc-borosilicate glass and inert ceramic filler, for passivation of semiconductors |
| G017-004* | Lead-borosilicate glass with an inert ceramic filler for passivation of semiconductors |
| G017-052* | Low melting lead-borate glass |
| G017-096R* | Lead-borosilicate glass for passivation of semiconductors |
| G017-230* | Composite glass for passivation of semiconductors, especially power transistors |
| G017-339* | Non-crystallizing, very low melting composite solder glass, consisting of lead-borate glass and inert ceramic filler.<br>Good match to materials with a CTE of 5 … 6 ppm/K. |
| G017-340* | Non-crystallizing, very low melting composite solder glass, consisting of lead-borate glass and inert ceramic filler |
| G017-388* | Passiviation glass for thyristors and high block rectifiers. Also usable as solder glass. |
| G017-393* | Non-crystallizing low melting composite solder glass with a lead-borate glass and an inert ceramic filler<br>The thermal expansion coefficient is well matched to alumina. |
| G017-712* | Low melting composite solder glass consisting of a lead-borate based glass and inert ceramic filler |
| G017-725* | Lead-borosilicate glass for passivation of diodes |
| G017-997* | Composite glass for passivation of silicon wafers, based on a lead-silicate glass and an inert ceramic filler |
| G018-133* | Passivation glass for sinter glass diodes |
| G018-197* | Low melting, lead-free passiviation glass |
| G018-200* | Lead-free passivation and solder glass |
| G018-205* | Zinc-borate glass suitable for hermetic capsulation of diodes and general sealing glass |
| G018-228* | Lead-containing composite solder glass for CTE range 7–8 |
| G018-229* | Lead-containing composite solder glass for soda-lime glass |
| G018-249* | Low melting lead-free solder glass |
| G018-250* | Low melting lead-free solder glass for the thermal expansion range of 7… 8 |
| G018-255* | Lead-free solder glass for CTE range 9 … 10 |
| G018-256* | Non-crystallizing, low melting lead-borate glass |
| G018-266* | High temperature sealing glass for $Al_2O_3$ |
| G018-281* | Glass-ceramic sealant for SOFC applications |
| G018-311* | Alkaline-free high temperature sealing glass for $ZrO_2$ ceramics |
| G018-339* | Alkaline-free high temperature sealing glass for $ZrO_2$ ceramics |
| G018-346* | Alkaline-free high temperature sealing glass for $Al_2O_3$ |
| G018-354* | Glass-ceramic sealant for SOFC applications |
| G018-358* | Alkaline-free high temperature sealing glass for $Al_2O_3$ |
| G018-381* | Glass-ceramic composite sealant for SOFC applications |
| G018-385* | SOFC sealing glass / High temperature sealing glass for $Al_2O_3$ |
| GM31107* | Glass sealant for SOFC applications |
| GS10 | Intermediate sealing glass |
| GS20 | Intermediate sealing glass |
| GS25 | Intermediate sealing glass |
| GS30 | Intermediate sealing glass |
| Mempax | Borosilicate glass manufactured as ultrathin glass |

***not available as tube.**

**Table 19.**

# Glasses for the Chemical Industry and Electrical Engineering ·

| 1 | 2 | 3 | 4 | | | 5 | 6 | | 7 | 8 |
|---|---|---|---|---|---|---|---|---|---|---|
| Glass no. | $\alpha_{20/300}$ | Transformation temperature $T_g$ | Glass temperature at viscosities | | | Density at 25 °C | Firing conditions | | Young's modulus | Poisson's-ratio |
| | | | $10^{13}$ dPa·s | $10^{7,6}$ dPa·s | $10^{4}$ dPa·s | | Firing Temp | Dwell time | | |
| | [$10^{-6}$/K] | [°C] | [°C] | [°C] | [°C] | [g/cm³] | °C | min | [$10^3$N/mm²] | μ |
| 8095 | 9.1 | 430 | 435 | 630 | 982 | 3.01 | – | – | 60 | 0.22 |
| 8100 | 9.6 | 465 | 465 | 655 | 960 | 3.28 | – | – | – | – |
| 8228 | 1.3 | 700 | 700 | 1135 | 1665 | 2.15 | – | – | – | – |
| 8229 | 2.0 | 600 | 637 | 930 | 1440 | 2.17 | – | – | – | – |
| 8230 | 2.7 | 570 | 590 | 915 | 1425 | 2.19 | – | – | – | – |
| 8240 | 4.7 | 790 | 795 | 1005 | 1305 | 2.67 | – | – | 83 | 0.23 |
| 8241 | 4.7 | 790 | 795 | 1005 | 1305 | 2.67 | – | – | 83 | 0.23 |
| 8242 | 4.7 | 465 | 480 | 715 | 1130 | 2.27 | – | – | – | – |
| 8245 | 5.1 | 505 | 515 | 720 | 1040 | 2.31 | – | – | 68 | 0.22 |
| 8250 | 5.0 | 490 | 500 | 720 | 1055 | 2.28 | – | – | 64 | 0.21 |
| 8252 | 4.6 | 720 | 725 | 935 | 1240 | 2.63 | – | – | 81 | 0.24 |
| 8253 | 4.7 | 790 | 795 | 1005 | 1305 | 2.7 | – | – | 83 | 0.23 |
| NEO 1730 | 4.5 | 715 | 725 | 935 | 1210 | 2.67 | – | – | – | – |
| 8270 | 5.0 | 490 | 505 | 705 | 1040 | 2.27 | – | – | 64 | 0.21 |
| 8271 | 5.2 | 505 | 515 | 715 | 1040 | 2.32 | – | – | 60 | 0.21 |
| 8326 | 6.6 | 565 | 570 | 770 | 1125 | 2.45 | – | – | 75 | 0.20 |
| 8330 | 3.3 | 525 | 560 | 825 | 1260 | 2.23 | – | – | 63 | 0.20 |
| 8337B | 4.1 | 440 | 465 | 705 | 1085 | 2.22 | – | – | 51 | 0.22 |
| 8341 | 4.04 | 577 | 600 | 840 | 1277 | 2.28 | – | – | 68 | 0.20 |
| 8347 | 3.3 | 525 | 560 | 825 | 1260 | 2.23 | – | – | 63 | 0.20 |
| 8350 | 9.1 | 525 | 530 | 720 | 1040 | 2.50 | – | – | 73 | 0.22 |
| 8360 | 9.1 | 465 | 470 | 575 | 745 | 2.66 | – | – | 85 | 0.23 |
| 8366 | 9.2 | 470 | 480 | 675 | 1015 | 2.61 | – | – | – | – |
| 8405 | 9.7 | 460 | 470 | 665 | 1000 | 2.51 | – | – | 65 | 0.21 |
| 8412 | 4.9 | 565 | 565 | 785 | 1160 | 2.34 | – | – | 73 | 0.20 |
| 8414 | 5.4 | 550 | 560 | 770 | 1165 | 2.42 | – | – | 71 | 0.19 |
| 8415 | 7.8 | 535 | 540 | 720 | 1050 | 2.50 | – | – | 74 | 0.21 |
| 8436 | 6.6 | 635 | – | – | 1100 | 2.77 | – | – | – | – |
| 8447 | 4.6 | 475 | 505 | 720 | 1045 | 2.26 | – | – | – | – |
| 8448 | 3.8 | 510 | 560 | 800 | 1210 | 2.25 | – | – | – | – |
| 8449 | 4.5 | 535 | 550 | 785 | 1150 | 2.29 | – | – | – | – |
| 8450 | 5.4 | 570 | 575 | 778 | 1130 | 2.44 | – | – | – | – |
| 8454 | 6.4 | 565 | 575 | 750 | 1070 | 2.49 | – | – | – | – |
| 8455 | 6.7 | 565 | – | 740 | 1030 | 2.44 | – | – | – | – |
| 8456 | 7.4 | 445 | – | 685 | 1145 | 2.49 | – | – | – | – |
| 8465 | 8.2 | 385 | – | – | – | 5.4 | 520 | 30 | – | – |
| 8470 | 10.0 | 440 | – | 570 | 748 | 2.80 | – | – | – | – |
| 8487 | 3.9 | 525 | 560 | 775 | 1135 | 2.25 | – | – | 66 | 0.20 |
| 8516 | 8.9 | 447 | 445 | 646 | 990 | 2.56 | – | – | 72 | 0.21 |
| 8531 | 9.1 | 435 | 430 | 585 | 820 | 4.31 | – | – | 52 | 0.24 |
| 8532 | 8.7 | 435 | 430 | 560 | 760 | 4.46 | – | – | 56 | 0.24 |
| 8625 | 9.2 | 514 | 520 | 710 | 1023 | 2.52 | – | – | 73 | 0.22 |
| 8650 | 5.1 | 475 | 475 | 625 | 885 | 3.57 | – | – | 62 | 0.23 |
| 8651 | 4.4 | 549 | 540 | 736 | 1034 | 2.91 | – | – | 59 | 0.24 |
| 8652 | 4.5 | 495 | 490 | 638 | 900 | 3.18 | – | – | 58 | 0.25 |
| 8660 | 4.1 | 550 | – | 830 | 1215 | 2.44 | – | – | – | – |

# Sealing Glasses

| 9 | 10 | 11 | | 12 | | 13 | 14 | 15 | | | 16 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Heat conductivity λ at 90 °C | $t_{k100}$ | Logarithm of the electric volume resistance in Ω cm at | | Dielectric properties for 1 MHz at 25 °C | | Refractive index nd ($\lambda_d$ = 587.6 nm) | Stress-optical coefficient K | Classes of chemical stability | | | Glass no. |
| [W/(m·K)] | [°C] | 250 °C | 350 °C | $\varepsilon_r$ | tanδ [$10^{-4}$] | | [$10^{-6}$ mm²/N] | Water | Acid | Alkaline solution | |
| 0.9 | 330 | 9.6 | 7.6 | 6.6 | 11 | 1.556 | 3.1 | 3 | 2 | 3 | 8095 |
| – | – | – | – | – | – | 1.595 | – | 3 | – | – | 8100 |
| – | – | – | – | – | – | – | – | – | – | – | 8228 |
| – | 350 | – | – | – | – | – | – | – | – | – | 8229 |
| – | 255 | – | – | – | – | – | – | – | – | – | 8230 |
| 1.1 | 630 | 13.0 | 11.0 | 6.6 | 15 | 1.546 | 2.7 | 1 | 2 | 2 | 8240 |
| 1.1 | 630 | 13.0 | 11.0 | 6.6 | 15 | 1.546 | 2.7 | 1 | 2 | 2 | 8241 |
| – | – | – | – | – | – | 1.480 | – | 2 | 4 | 3 | 8242 |
| 1.2 | 215 | 7.4 | 5.9 | 5.7 | 80 | 1.488 | 3.8 | 3 | 4 | 3 | 8245 |
| 1.2 | 375 | 10 | 8.3 | 4.9 | 22 | 1.487 | 3.6 | 3 | 4 | 3 | 8250 |
| 1.1 | 660 | – | 12 | 6.1 | 11 | 1.538 | 2.8 | 1 | 3 | 2 | 8252 |
| 1.1 | 630 | 13 | 11 | 6.6 | 15 | 1.547 | 2.7 | 1 | 2 | 2 | 8253 |
| – | – | – | – | – | – | 1.548 | – | 1 | 3 | 2 | NEO 1730 |
| 1.2 | 377 | 10.3 | 8.4 | 5.3 | 127 | 1.487 | 3.6 | 3 | 4 | 3 | 8270 |
| 1.1 | 365 | 10.0 | 8.2 | 5.3 | 60 | 1.502 | 4.0 | 3 | 4 | 3 | 8271 |
| 1.2 | 210 | 7.3 | 6.0 | 6.4 | 65 | 1.506 | 2.8 | 1 | 1 | 2 | 8326 |
| 1.2 | 250 | 8.0 | 6.5 | 4.6 | 37 | 1.473 | 4.0 | 1 | 1 | 2 | 8330 |
| 1.0 | 315 | 9.2 | 7.5 | 4.7 | 22 | 1.476 | 4.1 | 3 | 4 | 3 | 8337B |
| 1.2 | – | – | – | – | – | 1.479 | – | 1 | 1 | 2 | 8341 |
| 1.2 | 250 | 8.0 | 6.5 | 4.6 | 37 | 1.473 | 4.0 | 1 | 1 | 2 | 8347 |
| 1.1 | 200 | 7.2 | 5.7 | 7.2 | 70 | 1.514 | 2.7 | 3 | 1 | 2 | 8350 |
| – | 275 | 8.5 | 6.7 | 7.3 | 24 | 1.566 | 2.9 | 3 | 4 | 3 | 8360 |
| – | 280 | 8.6 | 6.8 | – | – | – | – | 3 | 1 | 2 | 8366 |
| 1.0 | 280 | 8.5 | 6.9 | 6.5 | 45 | 1.505 | 2.8 | 5 | 3 | 2 | 8405 |
| 1.2 | 215 | 7.4 | 6.0 | 5.7 | 80 | 1.492 | 3.4 | 1 | 1 | 2 | 8412 |
| 1.2 | 200 | 7.1 | 5.6 | 6.3 | 107 | 1.523 | 2.2 | 1 | 1 | 2 | 8414 |
| 1.1 | 180 | 6.7 | 5.3 | 7.1 | 113 | 1.521 | 3.2 | 2 | 2 | 2 | 8415 |
| – | – | – | – | – | – | – | – | 2 | 2 | 1 | 8436 |
| – | 270 | – | – | – | – | 1.478 | – | 4 | – | – | 8447 |
| – | 265 | – | – | – | – | 1.475 | – | 1 | – | – | 8448 |
| – | 350 | – | – | – | – | 1.480 | – | – | – | – | 8449 |
| – | 200 | – | – | – | – | – | – | – | – | – | 8450 |
| – | 210 | – | – | – | – | – | – | – | – | – | 8454 |
| – | – | – | – | – | – | – | – | – | – | – | 8455 |
| – | – | – | – | – | – | – | – | – | – | – | 8456 |
| – | – | – | – | – | – | – | – | – | – | – | 8465 |
| – | 295 | – | – | – | – | – | 3.7 | 2 | – | – | 8470 |
| 1.2 | 300 | 8.3 | 6.9 | 4.9 | 36 | 1.479 | 3.6 | 4 | 3 | 3 | 8487 |
| 1.1 | 250 | 8.1 | 6.4 | 6.5 | 25 | 1.516 | 3.0 | 3 | 1 | 2 | 8516 |
| 0.7 | 450 | 11 | 9.8 | 9.5 | 9 | 1.700 | 2.2 | 1 | 4 | 3 | 8531 |
| 0.7 | 440 | 11 | 9.4 | 10.2 | 9 | 1.724 | 1.7 | 1 | 4 | 3 | 8532 |
| 1.1 | 210 | 7.2 | 5.8 | 7.1 | 68 | 1.525 | – | 3 | 1 | 2 | 8625 |
| 0.5 | – | – | – | 7.6 | 33 | 1.618 | 2.8 | 1 | 4 | 3 | 8650 |
| 0.9 | – | 11.2 | 10.0 | 6.0 | 31 | 1.552 | 3.6 | 1 | 4 | 3 | 8651 |
| 0.9 | – | – | – | 6.9 | 35 | 1.589 | 3.4 | 1 | 4 | 3 | 8652 |
| – | 550 | 12.7 | 10.7 | – | – | 1.486 | – | 3 | 3 | 3 | 8660 |

| 1 | 2 | 3 | 4 | | | 5 | 6 | | 7 | 8 |
|---|---|---|---|---|---|---|---|---|---|---|
| Glass no. | $\alpha_{20/300}$ | Transformation temperature $T_g$ | Glass temperature at viscosities | | | Density at 25 °C | Firing conditions | | Young's modulus | Poisson's-ratio |
| | | | $10^{13}$ dPa·s | $10^{7,6}$ dPa·s | $10^{4}$ dPa·s | | Firing Temp | Dwell time | | |
| | [$10^{-6}$/K] | [°C] | [°C] | [°C] | [°C] | [g/cm³] | °C | min | [$10^3$N/mm²] | μ |
| 8689 | 3.8 | 515 | 565 | 770 | 1110 | 2.27 | – | – | 65 | 0.20 |
| 8800R | 5.5 | 565 | 570 | 790 | 1175 | 2.34 | – | – | 73 | – |
| AF32 eco | 3.2 | 717 | 686 | 731 | 970 | 2.43 | – | – | 74.8 | 0.24 |
| Borofloat | 3.25 | 525 | 560 | 820 | 1260 | 2.23 | – | – | 64 | 0.20 |
| B270®i | 9.4 | 542 | 507 | 535 | 711 | 2.56 | – | – | 71 | 0.22 |
| D263T eco | 7.2 | 557 | 529 | 557 | 736 | 2.51 | – | – | 72.9 | 0.21 |
| G017-002 | 3.7 | 545 | – | 640 | – | 3.25 | 700 | 10 | – | – |
| G017-004 | 4.1 | 440 | – | 660 | – | 3.22 | 740 | 5 | – | – |
| G017-052 | 11.7 | 308 | – | 347 | – | 6.65 | 410 | 15 | 43 | – |
| G017-096R | 4.8 | 456 | – | 650 | – | 3.54 | 680 | 5 | – | – |
| G017-230 | 4.2 | 440 | – | 650 | – | 3.45 | 700 | 4 | 62 | 0.22 |
| G017-339 | 4.7 | 325 | – | 415 | – | 4.3 | 510 | 30 | – | – |
| G017-340 | 7.0 | 315 | – | 360 | – | 4.8 | 420 | 15 | 60 | 0.28 |
| G017-388 | 3.6 | 550 | – | 645 | – | 3.4 | 700 | 5 | – | – |
| G017-393 | 6.5 | 320 | – | 370 | – | 4.8 | 420 | 15 | 58 | – |
| G017-712 | 5.3 | 375 | – | – | – | 4.0 | 510 | 10 | – | – |
| G017-725 | 4.9 | 468 | – | 620 | 874 | 3.59 | 670 | 10 | 58 | 0.22 |
| G017-997 | 4.4 | 485 | – | – | – | 3.45 | 760 | 20 | – | – |
| G018-133 | 4.8 | 463 | – | – | – | 3.47 | 690 | 30 | 60 | 0.22 |
| G018-197 | 4.4 | 557 | – | – | – | 3.76 | 675 | 10 | – | – |
| G018-200 | 4.6 | 557 | – | – | – | 3.63 | 665 | 10 | – | – |
| G018-205 | 4.45 | 541 | – | 632 | – | 3.83 | 690 | 10 | – | – |
| G018-228 | 7.6 | 311 | – | – | – | 5.0 | 400 | 15 | – | – |
| G018-229 | 8.3 | 310 | – | – | – | 5.44 | 400 | 15 | – | – |
| G018-249 | 10.1 | 365 | – | – | – | 7.13 | 500 | 10 | 68 | 0.31 |
| G018-250 | 7.0 | 380 | – | – | – | 5.7 | 510 | 10 | – | – |
| G018-255 | 9.4 | 396 | – | – | – | 6.71 | 520 | 15 | 76 | 0.24 |
| G018-256 | 9.2 | 316 | – | – | – | 5.79 | 420 | 15 | – | – |
| G018-266 | 6.9 (glassy) | 585 | – | 673 | 780 | 4.55 | 770 | 15 | 111 | 0.30 |
| G018-281 | 12.0 | 652 | 656 | 864 | 1196 | 2.72 | 960 | 30 | – | – |
| G018-311 | 9.1 (glassy)<br>9.9 (p.c.)** | 622 | 690 | – | 873 | 3.8 | 850 | 30 | – | – |
| G018-339 | 9.2 (p.c.)** | 627 | – | – | – | – | 990 | 15 | – | – |
| G018-346 | 7.3 (glassy) | 720 | – | – | – | – | 1270 | 15 | – | – |
| G018-354 | 9.2 | 643 | – | 753 | 908 | 3.9 | 850 | 30 | – | – |
| G018-358 | 8.5 (glassy)<br>8.8 (p.c.)** | 658 | – | – | – | 3.24 | 940 | 15 | – | – |
| G018-381 | 4.6 (glassy)<br>12.0 (a.c.)** | 652 | – | – | – | 2.3 | 900 | 60 | – | – |
| G018-385 | 8.4 (p.c.)** | 992** | 696 | 808 | 862 | 3.14 | 950 | 30 | 123** | – |
| GM31107 | 10.0 (a.c.)** | 532 | – | 632 | 750 | 3.7 | 700 | 30 | – | – |
| GS10 | 1.25 | 700 | 730 | 1195 | 1710 | 2.17 | – | – | – | – |
| GS20 | 1.9 | 690 | 730 | 1175 | 1680 | 2.22 | – | – | – | – |
| GS25 | 2.65 | 610 | 640 | 1055 | 1605 | 2.21 | – | – | – | – |
| GS30 | 3.05 | 620 | 635 | 1055 | 1570 | 2.24 | – | – | – | – |
| Mempax | 3.26 | 532 | 528 | 570 | 831 | 2.22 | – | – | 62.7 | 0.20 |

**Table 20.** Characteristic values of technical glasses

**partially crystalline

| 9 | 10 | 11 | | 12 | | 13 | 14 | 15 | | | 16 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Heat conductivity λ at 90 °C | $t_{k100}$ | Logarithm of the electric volume resistance in Ω cm at | | Dielectric properties for 1 MHz at 25 °C | | Refractive index nd ($\lambda_d$ = 587.6 nm) | Stress-optical coefficient K | Classes of chemical stability | | | Glass no. |
| [W/(m·K)] | [°C] | 250 °C | 350 °C | $\varepsilon_r$ | tanδ [$10^{-4}$] | | [$10^{-6}$ mm²/N] | Water | Acid | Alkaline solution | |
| 1.2 | 314 | 9.1 | 7.5 | 5.0 | 20 | 1.498 | 3.9 | 3 | 3 | 3 | 8689 |
| – | 191 | 7.0 | 5.7 | 5.9 | 143 | 1.490 | 3.3 | 1 | 1 | 2 | 8800 |
| – | – | 11.9 | 10.0 | 5.1 | – | 1.5100 | – | HGB1 | S4 | A3 | 8265 |
| 1.2 | 250 | 8.0 | 6.5 | 4.6 | 37 | 1.4714 | 4.0 | HGB1 | S1 | A2 | 8330 |
| 1.02 | – | 7.8 | 6.2 | 7.5 | – | 1.5230 | – | HGB3 | S2 | A1 | 0090 |
| – | – | 8.2 | 6.5 | 6.7 | – | 1.5231 | – | HGB1 | S2 | A2 | 0988 |
| – | – | – | – | 6.8 | 37 | – | – | – | – | – | G017-002 |
| – | – | – | – | – | – | – | – | – | – | – | G017-004 |
| – | – | – | – | – | – | – | – | – | – | – | G017-052 |
| – | – | – | – | – | – | – | – | – | – | – | G017-096R |
| – | – | – | – | – | – | – | – | – | – | – | G017-230 |
| – | – | – | – | – | – | – | – | – | – | – | G017-339 |
| – | – | – | – | – | – | – | – | – | – | – | G017-340 |
| – | – | – | – | – | – | – | – | – | – | – | G017-388 |
| – | – | – | – | – | – | – | – | – | – | – | G017-393 |
| – | – | – | – | – | – | – | – | – | – | – | G017-712 |
| – | – | – | – | – | – | – | – | – | – | – | G017-725 |
| – | – | – | – | – | – | – | – | – | – | – | G017-997 |
| – | – | – | – | – | – | – | – | – | – | – | G018-133 |
| – | – | – | – | – | – | – | – | – | – | – | G018-197 |
| – | – | – | – | – | – | – | – | – | – | – | G018-200 |
| – | – | – | – | – | – | – | – | – | – | – | G018-205 |
| – | – | – | – | – | – | – | – | – | – | – | G018-228 |
| – | – | – | – | – | – | – | – | – | – | – | G018-229 |
| – | – | – | – | – | – | – | – | – | – | – | G018-249 |
| – | – | – | – | – | – | – | – | – | – | – | G018-250 |
| – | – | – | – | – | – | – | – | – | – | – | G018-255 |
| – | – | – | – | – | – | – | – | – | – | – | G018-256 |
| – | – | – | – | – | – | – | – | – | – | – | G018-266 |
| – | – | – | – | – | – | – | – | – | – | – | G018-281 |
| – | – | – | – | – | – | – | – | – | – | – | G018-311 |
| – | – | – | – | – | – | – | – | – | – | – | G018-339 |
| – | – | – | – | – | – | – | – | – | – | – | G018-346 |
| – | – | – | – | – | – | – | – | – | – | – | G018-354 |
| – | – | – | – | – | – | – | – | – | – | – | G018-358 |
| – | – | – | – | – | – | – | – | – | – | – | G018-381 |
| – | – | – | – | – | – | – | – | – | – | – | G018-385 |
| – | – | – | – | – | – | – | – | – | – | – | GM31107 |
| – | 420 | 10.5 | 8.9 | – | – | – | – | – | – | – | GS10 |
| – | 465 | 11.1 | 9.4 | – | – | – | – | – | – | – | GS20 |
| – | 440 | 10.7 | 9.0 | – | – | – | – | – | – | – | GS25 |
| – | 440 | 10.8 | 9.1 | – | – | – | – | – | – | – | GS30 |
| – | – | 8.1 | 6.6 | 4.8 | – | 1.4715 | – | HGB1 | S1 | A2 | 8330 |

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| Product group | : | Specialty Coatings |
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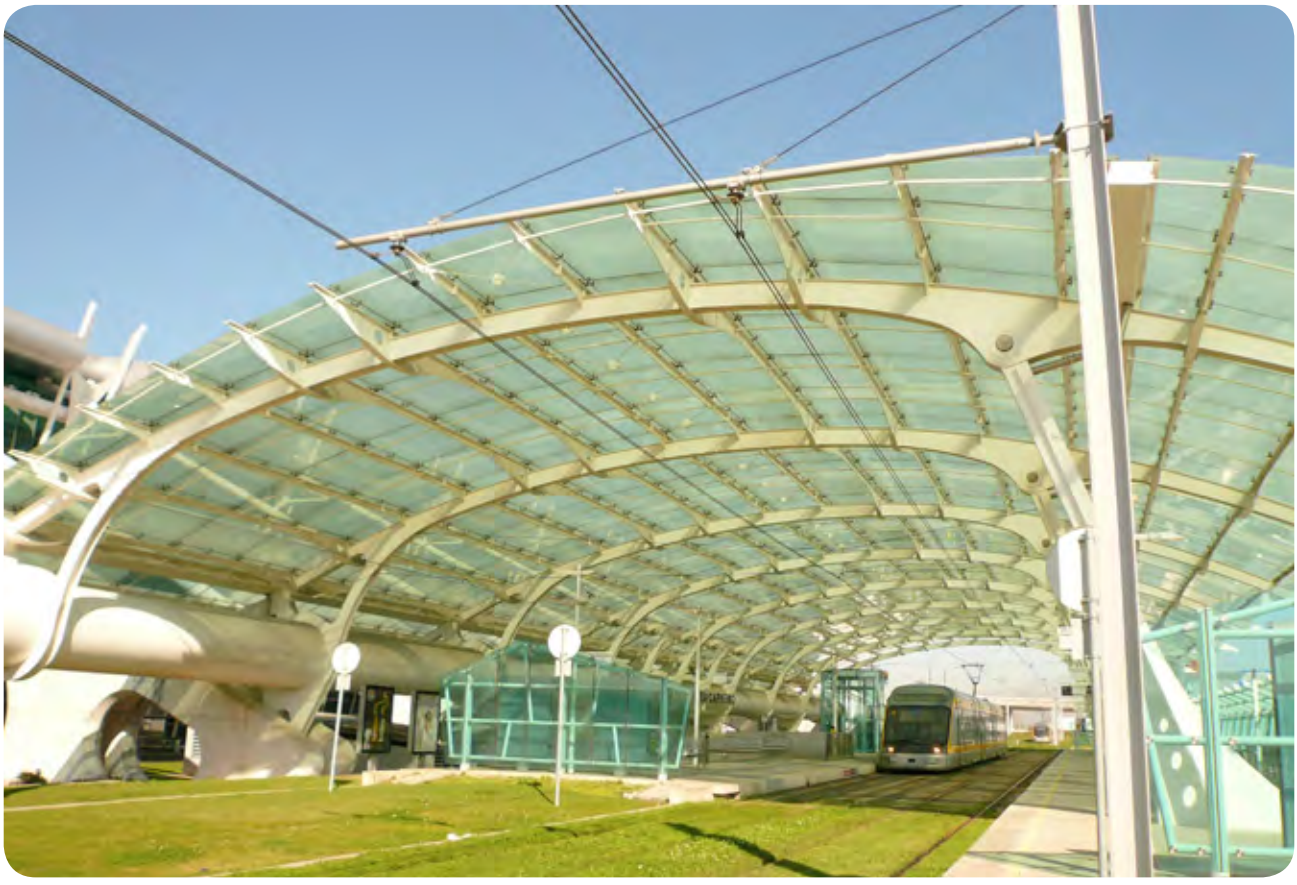
| Date | : | April 2011 |



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# Vindico HP® specification

## HYDROPHILIC PROTECTION FOR GLASS & CERAMICS:

**Vindico – Meaning "PROTECTION" in Latin and superior performance in any language.** Vindico HP® protects glass from contamination like dust, bird droppings, salt, industrial/automotive emissions and corrosion from limescale and water spots. Vindico HP® reduces maintenance on these surfaces and makes them easy to clean and remain cleaner longer. Common applications include windows, structural glazing, skylights, sunrooms, conservatories, greenhouses and other exterior glass.

Vindico HP® is a highly advanced technology that has undergone continual refinement and proven to withstand UV, weathering, and abrasion testing.

**This means Vindico HP®:**

- Provides the newest technological advancements
- Offers the fastest and easiest application (no downtime)
- Low cost application – no expensive equipment
- Does not require expensive maintenance products
- Completely pH neutral without acid curing

**Vindico HP® has been independently tested and verified to:**

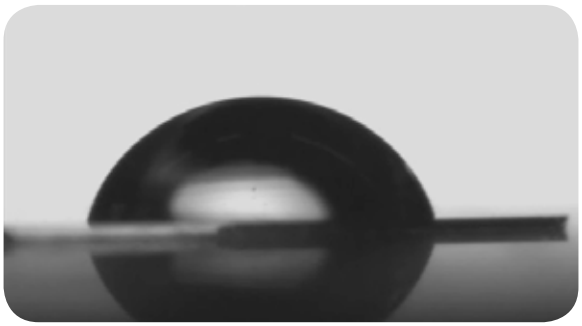
- Improve the cleanliness of glass
- Provide greater durability than competitive products
- Offer greater abrasion resistance – protection that lasts
- Reduces maintenance and keeps glass cleaner

## CHEMISTRY:

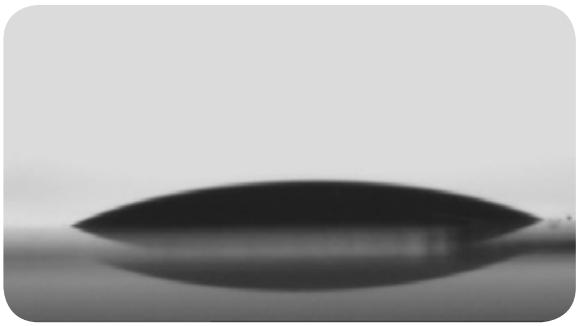
Vindico HP® creates an easy clean, hydrophilic (water loving) surface on glass and vitreous surfaces. This reaction causes water to flatten out and slide off the glass, rinsing away contamination and greatly reducing water spots.

In addition to the hydrophilic properties of Vindico HP® is its ability to protect glass from mineral deposits, rust, discoloration and permanent damage. This means glass treated with Vindico HP® remains cleaner longer and is always easier to clean.

Vindico HP® provides such a durable technology that it does not require expensive or specialty cleaning products. Simply use any cleaner formulated for glass.



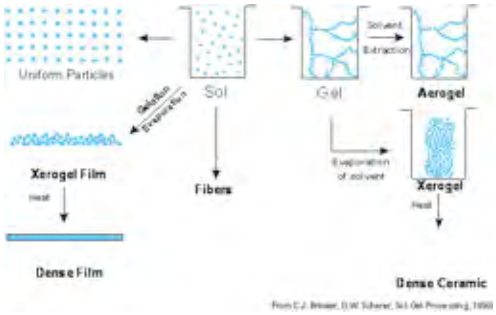
Hyddrophobic



Hydrophilic

## How does it work?

Vindico HP® is an advanced SiOx (Silicon Oxide) hydrophilic coating consisting of a two component chemical sol-gel that offers key advantages for glass.. Multiple chemical traits are combined into a single coating. Vindico HP® joins nano particles for maximum surface coverage and long chemical chains for increased bonding – sol-gels offer incredible adhesion, durability and wear resistance (Vindico HP has passed 50,000 abrasion tests with no effect).




For windows and exterior glass, there are many tests that can be performed to demonstrate clean glass, but one of the most precise and measurable is light transmission. Dust, pollution, water spots – anything that gets on a glass surface can be measured using light transmission, including coatings. Technologies used for easy clean purposes should keep glass as clean as possible for increased beauty, clarity and brightness – they should NOT damage transmission of light.

Independent testing in both laboratory and outside conditions confirm that Vindico HP® reduces contamination by as much as 50%. This provides for a major increase in light transmission when compared to untreated glass and other coatings. In addition, Vindico HP does not decrease light transmission on glass – this is not the case with many coatings and technologies on the market.

Vindico HP® is based on inorganic compounds, meaning it is completely UV stable. Technologies based on organic properties are not UV stable, meaning they deteriorate in sunlight – not a desirerable trait for exterior use.

Vindico HP® has passed European EN-1096 Standards for glass coatings and the even more demanding IEC 1215 standards for use with photovoltaic (solar) glass.

## Independent Testing

Vindico HP® has also been independently tested and benchmarked by INNOVENT E.V., S.A., TNO Laboratories and our own internal testing and research departments.

These independent studies include long term testing to determine the effects that exposure to exterior forces and weathering has on glass. While ordinary glass had a 9% decrease in light transmission due to weathering and natural contamination, Vindico HP® continued to perform at the highest levels, keeping the glass cleaner and clearer for a 50% improvement over ordinary glass!!

Additionally, abrasion testing and accelerated weathering testing of Vindico HP shows durability expectations of more than 30 years!!

## Hydrophilic vs. Hydrophobic

The institute INES in France performed testing of hydrophobic coatings on glass used in PV modules and compared them to ordinary glass. While it may appear to be a leap for these studies to have any value for windows, sunrooms and other exterior glass – both are affected by the same weathering conditions and contamination factors and the results can be precisely measured.

Initial tests showed a 1% decrease in light transmission with the hydrophobic technology due to light interference, as testing continues, the hydrophobic coating further deteriorated light transmission by 20% or more.

The contamination of the glass was atributed to the water spots left on the glass as water droplets dried. Each time it rained or water was applied to the glass these water spots multipled, increasing contamination and further reducing light transmission.

Additionally, AGC, Cardinal and St. Gobain also benchmarked coatings in the technical committee for EN norms – TC24 (European testing standards) which is described as the Haze test. Hydrophobic coatings returned the poorest results.

Vindico HP® is your best choice for keeping all exterior glass cleaner and clearer. It protects against all forms of contamination and has been proven by independent tests to provide long term durability and is a superior choice over hydrophilic technologies.
Make sure you offer your customers a product that performs to the highest standards!!!

## Instructions

Simple Application leading to simply amazing results

Ensure glass is clean and dry.

Spray Vindico HP on glass surface.

Wipe surface to remove any excess product – practiced application will result in spray technique that does not require wiping glass after spraying.

Let air dry – less than 1 minute at room temperatures.

Pack and ship – no additional cure time* or post washing process necessary.

*Full cure may require up to 24 hours – however, glass can be handled, wrapped, shipped or installed prior to full cure.

Vindico HP is a non-acid curing product; meaning glass does not require taping off or additional protection measures for application.

Vindico is compatible with most silicones and butyls.

Contact Applied Surface Technologies for further specifications and compatibility information.

## Packaging

HDPE containers
1 liter (10 containers per box).
5 liter container (4 containers per box)
30 liter container

## How to order

contact:
Vindico Surface Technologies
Postbus 196, 3370 AD Hardinxveld-Giessendam
Transportweg 11, 3371 MA Hardinxveld-Giessendam
The Netherlands
tel +31 (0) 184 - 675 875
fax +31 (0) 184 - 630 036
p.bastianen@vindico.info
jzaman@vindico.info
**www.vindico.info**

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VINDICO®

*Special chemistry for Glass*

# Residue on Glass

***The glass cleaning recommendations in this document are offered by Vitro (formerly PPG Industries) for specific projects with severe residue and dirt build-up and should not be used as standard cleaning procedures.***

**Glass**

For over two thousand years, the lustrous, hard and inert characteristics of glass, coupled with its transparency, have made it one of the world's most desirable and used building materials.

Glass has been successfully used in the construction industry for many years on thousands of projects involving billions of square feet of glass.

***NO VITRO GLASS, BY ITSELF, EXUDES, LEACHES OR BLEEDS ANY RESIDUE OR STAIN CAUSING MATERIALS.***

**Runoff and Glass Damage**

When water reaches a building, it is reflected, absorbed into the building materials, or allowed to run down the façade. When this water is permitted to run down over masonry, sealants, and other building materials, and onto the glass, the water can carry with it contaminants that may react with and adhere to the glass surface. These contaminants could lead to a residue that is difficult to remove, a stain that cannot be removed, or the chemical attachment of certain minerals to the glass surface.

*The following paragraph was excerpted from Metal Curtain Wall, Window, Store Front and Entrance, Guide Specifications Manual published in 1976 by Architectural Aluminum Manufacturers Association.*

*"Glass may be damaged, etched or stained by a number of materials typically used at a job site. Surface damage may be caused by weld splatter and wind-blown debris. Alkaline materials such as concrete wash off and certain cleaning agents may chemically attack the glass surfaces. Rust (iron oxide) will not usually deteriorate the glass surface, but may be very difficult to remove. Silicone concrete sealing materials can discolor glass surfaces; it is a good practice to protect glass surfaces whenever practical during construction of the building. Special attention should be paid to single-glazed reflecting glasses. These are not any more susceptible to damage than uncoated glasses. However, scratches and other damage to the coating are more noticeable."*

**Silicates**

While the above paragraph is generally true, it contains some information that deserves clarification. It states that alkaline materials such as concrete wash off may chemically attack the glass surfaces. What actually happens is this: When rainwater makes contact with a concrete surface, small amounts of silicate material dissolve into the water. If these dissolved silicate solutions are allowed to dry on glass in the building, the result is a tenacious, water-insoluble deposit that is chemically bonded to the glass and resists conventional cleaning agents. The chemical bond occurs as quickly as evaporation to dryness occurs, and is as likely to occur in mid-winter as other seasons. With repeated run down and evaporation of silicate solutions the permanent deposits can build up and become quite unsightly.

**Masonry**

Staining, and, etching of glass can result from substances released from concrete facades and concrete window frames. Rainfall can permeate concrete, then leach alkaline materials from it, and deposit them on the glass. In some instances, this may cause surface staining and etching.

Concrete frames at window heads should be designed so that any runoff is directed away from the glass. Edge drips and a second drip, as another line of defense, should be provided. Pre-

# Residue on Glass

cast panels and all other concrete for outdoor walls should be processed for thorough mixing, full hydration, and complete curing. Concrete surface treatments (with acid, sandblasting, bush-hammering, grouting, waterproofing, etc.) must be completed before glazing begins; any loose particles resulting from these operations should be removed by normal wash, rinse, and dry cleaning.

It is essential that these surface treatments be completed prior to glazing. Vitro's experience verifies that if these surface treatments are performed while glass is in place, the risk of permanent damage to the glass is great, and complete replacement is usually the only practical remedy for damaged glass.

Glass should be examined at least monthly during construction when it is installed adjacent to or below concrete or other masonry surfaces that are exposed to weather. When inspection reveals dirt, scum, and other deposits or staining, glass should be immediately washed.

**Sealants**

Organic sealants used in today's glazing systems may exude, bleed, or leach solvents, oils and/or plasticizers, etc. under normal weathering conditions.

Depending on the type of sealant used and the weathering conditions encountered, residue from sealants can vary dramatically in content, degree, and the time period over which the residue continues to exude from the sealant. Generally, the degree of residue from sealants will diminish asymptotically over time.

In the great majority of projects, frequent cleaning of glass will remove deposits or residue using normal wash and rinse glass cleaning methods.
When residue from sealants is allowed to remain in contact with glass surfaces over a long period of time without frequent washing of the glass, the residue may become tenaciously bonded to the surface of the glass due to normal weathering. If the residue is permitted to have a long residence time, very costly cleaning techniques may be required to remove the residue from glass surfaces.

Due to exuding, leaching or bleeding, sealants need not necessarily be in direct contact with glass to produce a residue on glass. Residues from metal expansion joint sealants, parapet sealants, and metal and masonry weather-sealants, may still run down and deposit on the glass surfaces, either by gravity or through the action of rain.

On projects where residue build-up from sealants has occurred, it cannot be Vitro's responsibility to analyze these residues to determine their source, nature or composition. Because there are so many sealants available in the construction industry, Vitro cannot effectively analyze them all, or comment on their performance or recommend their use.

**Metals**

Weathering steels, for example, release oxides while "aging". These oxide deposits should be removed from glass by regular cleaning methods initiated early during construction. If the metal oxides are permitted to wash over glass and are permitted to accumulate, they can leave a deposit that is tenaciously adhered, requiring costly cleaning techniques to remove the residue from the glass surface.

# Residue on Glass

### Glass Fabrication Processing Marks

Window fabrication and installation practices utilize many means to process, store, and install the glass. These means are generally used to prevent glass to glass contact or glass damage from occurring, and to safely handle the glass either manually or automatically. These means may include but are not limited to the use of separator pads, conveyor belts, conveyor rollers, brushes, the use of suction cups, etc. While the use of these devices during the fabrication and installation process does not leave a visible residue on the glass surface, they do change the surface condition of the glass which could provide for a visual appearance under certain conditions. For example when water would bead up on the glass surface from either condensation, cleaning or rain, the outline of the processing contact may become visible. The different water beading patterns can create an outline with distinct lines of demarcation which can take the shape of the device that had previously contacted the glass surface in this area.

While this appearance would be noticeable under certain conditions, it does not affect the functionality, performance, or longevity of the glass. It is possible that this condition could dissipate over time with normal exposure to the elements and regular glass cleaning. It may be possible to immediately minimize or remove the surface differences present by following the cleaning procedure in Attachment C. Use caution with this cleaning method, test a small area first, as glass scratching may occur if light pressure is not used.

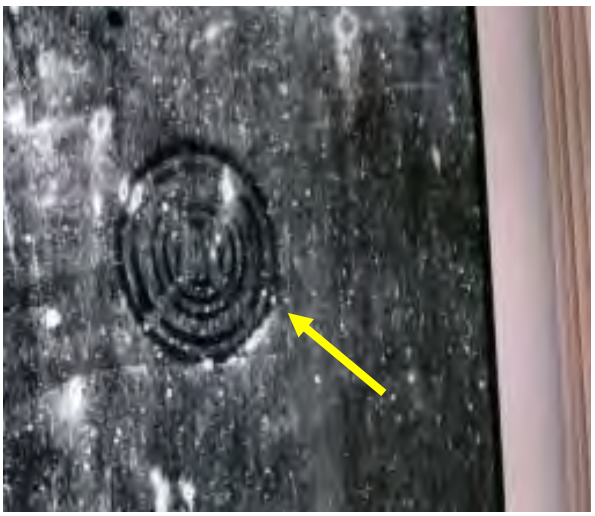

*Photo Above shows an installed window with heavy condensation on Glass. Different patterns are visible within the condensation including the outline of a Vacuum Cup mark which may have been used to handle the glass during fabrication or installation. There are no visible marks present on this glass in the absence of condensation.*

*Photo Above shows an installed window with heavy condensation on Glass. Different patterns are visible within the condensation including the outline of separator pad marks on glass. As above there are no visible marks present on this glass in the absence of condensation.*

# Residue on Glass

## Cleaning Recommendations

In situations where residue build-up or processing marks may have occurred, building owners and building maintenance supervisors may wish to consider cleaning procedures as indicated in Attachments A, B, and C. Cleaning procedures in Attachments B and C are intended for evaluation by building owners and maintenance supervisors and should be conducted on a selected sample (5 to 10 lites) of glass to determine: (1) their effectiveness and (2) estimated costs.

The cleaning procedures shown on Attachments A, B, and C can be recommended, evaluated, and used on Vitro products with non-low-e coated surfaces. This would include all Vitro clear and tinted products, monolithic *Solarcool*® or *Vistacool*®, and any IG units with Vitro *Solarban*®, *Sungate*®, *Solarcool*®, *Vistacool*® coatings facing the airspace of the IG unit.

The indicated glass cleaning procedures have been successfully demonstrated on projects having a rundown residue. However, if the cause of the residue deposit on glass is not corrected, it is likely that recontamination and residue build-up will recur.

After evaluation of these cleaning methods, their costs and effectiveness, it may be found that the only practical remedy for tenaciously bonded residue on glass surfaces is replacement of glass and modification of the glazing system to avoid recontamination.

## Design Recommendations

Early in the design stage, architects should consider glazing details designed to avoid water run-off onto glass surfaces. The use of reveals, splays, flashing, drips, etc. from sealants, masonry or metals can minimize run-off and avoid the deposition of residue onto the glass.

Location of water sprinklers in relation to glass surfaces should also be considered early in design. Direct or windblown hard water spray from water sprinklers can produce tenaciously bonded inorganic residues on glass surfaces. If spraying is repeated and/or wet, dry spray cycles are permitted to remain in contact with glass surfaces, for even short periods of time, costly cleaning procedures such as those recommended in Attachment C may be required.

Extended periods of cyclic water spray without frequent cleaning of glass may allow residue build-up to develop which cannot be removed by cleaning procedure in Attachment C. Glass replacement may be the only practical remedy.

Well-designed glazing surrounds that minimize run-off, combined with a review and recommendations from responsible material suppliers, will help eliminate residue build-up. Long-term beauty and performance of glass surfaces that architects and owners have reasonably come to expect over the centuries will thereby be assured.

# Residue on Glass

**For detailed cleaning procedures**

**See the following ATTACHMENTS A, B, and C**

# Residue on Glass

**ATTACHMENT A**

**Recommended Standard Glass Cleaning Procedure**

1. Apply mild soap, mild detergent, LEPTYNE®* solvent, xylene, toluene, mineral spirits or naphtha solvents to glass either by spraying or using a clean, grit-free cloth or sponge saturated with cleaning solution. Complete coverage of area to be cleaned is a necessity. For ease in cleaning, an area not exceeding 10 to 15 square feet is recommended. When using solvents, be careful not to damage glazing or insulating unit seals by overgenerous application of solvent. In addition, comply with solvent manufacturer's directions on label for toxicity, handling and flammability warnings.
2. Wipe the above cleaning solutions on the glass in a circular motion, applying light to moderate pressure; Approximately 3 to 5 passes of the affected area may be required to remove the residue. Fewer or more passes may be required, depending on the adhesion and severity of the residue.
3. Rinse the glass surface immediately with generous amounts of clean water, removing the cleaning solution from the glass surface.
4. Using a squeegee or clean, lint-free dry cloth, remove water from the glass surface.
5. If glass residue is still evident, repeat steps 1, 2, 3, and 4.

**Important Notes:**

1. Do not clean glass when glass is exposed to direct sunlight.
2. Glass should be cleaned by starting at the top of the building, systematically working down to glass installed on lower levels. This technique reduces the possibility of residue and cleaning solution rundown on glass previously cleaned.

*LEPTYNE® is a registered trademark of PPG Industries, Inc.

***The glass cleaning recommendations in this document are offered by Vitro for specific projects with severe residue and dirt build-up and should not be used as standard cleaning procedures.***

# Residue on Glass

**ATTACHMENT B**

**Recommended Glass Cleaning Procedure with RD-10 Detergent**

For Evaluation by Building owner or Maintenance Supervisor

1. Make a solution of RD-10 detergent and water, 1 part by volume RD-10 to 5 parts tap water.
2. Apply RD-10 solution on glass by spraying, or using a hand pump spray bottle. Using a soft damp cloth lightly spread the RD-10 water solution over an area of 10 to 15 square feet. Complete coverage of area to be cleaned is a necessity. For ease in cleaning, an area not exceeding 10 to 15 square feet is recommended.
3. Leave RD-10 solution on glass for 30 seconds to 1 minute.
4. With a damp, clean lint-free cloth, wipe the RD-10 solution on the glass-in a circular motion, applying light to moderate pressure. Approximately 3 to 5 passes of the affected area may be required to remove the residue. Fewer or more passes may be required, depending on the adhesion and severity of the residue.
5. Rinse the glass surface immediately with generous amounts of water, cleaning off all RD-10 solution from the glass.
6. Using a squeegee or clean lint-free dry cloth, remove water from the glass surface,
7. If glass residue is still evident, repeat steps 2, 3, 4, 5, and 6.

**Important Notes:**

1. Do not clean glass when glass is exposed to direct sunlight.
2. Glass should be cleaned by starting at the top of the building, systematically working down to glass installed on lower levels. This technique reduces the possibility of residue and cleaning solution rundown on glass previously cleaned.

RD-10 detergent can be obtained from:

The Rockland Corporation
12215 E. Skelly Drive
Tulsa, Oklahoma, 74128
(918) 437-RD10

***The glass cleaning recommendations in this document are offered by Vitro for specific projects with severe residue and dirt build-up and should not be used as standard cleaning procedures.***

# Residue on Glass

**ATTACHMENT C**

**Recommended Glass Cleaning Procedure with Cerium Oxide**

For Evaluation by Building Owner or Maintenance Supervisor

1. If using Cerium Oxide power, make a paste with the Cerium Oxide and water approximately 3 parts Cerium Oxide to 1 part water.
2. If using the Cerium Oxide paste, use the paste directly from the container.
3. Using a clean, lint-free cloth, wipe the Cerium Oxide paste on the glass in a circular motion with light pressure (two to four pounds). Cerium Oxide is an abrasive and, therefore, scratching could result if light pressure is not used. For ease in cleaning, an area not exceeding five square feet is recommended. Approximately three to five passes of the affected area may be required, depending on the adhesion and severity of the residue.
4. Rinse the glass surface immediately after Cerium Oxide cleaning with generous amounts of clean water, removing the Cerium Oxide paste from the glass
5. Using a squeegee or clean, lint-free dry cloth, remove water from the glass surface
6. If glass residue is still evident, repeat steps 3, 4, and 5
7. For evaluation of fabrication processing marks, lightly mist the surface with clean water. If marking is still evident, repeat steps 3, 4, and 5.

Only optical grade Cerium Oxide should be used, which can be obtained from chemical supply companies. A source for Cerium Oxide is:

1. Universal Photonics, Inc.
   85 Jetson Lane
   Central Islip, NY 11722
   (516) 935-4000
   Powder Part Number BA2018NS - Unicer 18, (1pound package - Powder)
   Paste Part Number BA2018PASTE – Unicer 18, (1pound container – Paste)

**Important Notes:**

1. Do not clean glass when glass is exposed to direct sunlight
2. Recommended to clean glass by starting at the top of the building, systematically working down to glass installed on lower levels. This technique reduces the possibility of residue and cleaning solution rundown on glass previously cleaned.

***The glass cleaning recommendations in this document are offered by Vitro for specific projects with severe residue and dirt build-up and should not be used as standard cleaning procedures.***

# Residue on Glass

| HISTORY TABLE | | |
|---|---|---|
| ITEM | DATE | DESCRIPTION |
| Original Publication | 11/30/1981 | |
| Revision #1 | 1/10/2002 | Revised & transferred to TD-107 |
| Revision #2 | 11/6/2006 | Added Glass Fabrication Processing Marks section and pictures. |
| Revision #3 | 10/4/2016 | Updated to Vitro Logo and format |
| Revision #4 | 1/4/2018 | Updated Cerium Oxide source in Attachment C, removed reference to SG300 and SG500 on page 4. |
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This document is intended to inform and assist the reader in the application, use, and maintenance of Vitro Flat Glass products. Actual performance and results can vary depending on the circumstances. **Vitro makes no warranty or guarantee as to the results to be obtained from the use of all or any portion of the information provided herein, and hereby disclaims any liability for personal injury, property damage, product insufficiency, or any other damages of any kind or nature arising from the reader's use of the information contained herein.**

# JHB Arts
Consultants

April 27, 2021

**Claremont McKenna College**
500 East Ninth Street, Bauer North
Claremont, CA 91711
Attn: Kimberly Shiring

| | |
|---|---|
| Artist: | Pae White, Pae White Studio |
| Artwork: | *Qwalala* |
| Date of Fabrication: | 2019 - 2023 |
| Dimensions: | 2.49m x 36m x 10.26m (98" x 1,416" x 404") |
| Artwork Weight: | 69,000 kg (152,119 lb) |
| Materials: | 3,000 Cast Glass Bricks, Structural Glazing Sealant |
| Glass Fabrication: | Poesia Glass Studio |
| Engineering: | Schlaich Bergermann Partner |
| Installation: | Trademark Concrete |

JHB Arts
Consultants

# General Care and Maintenance:

## I. Introduction

### A. Use Common Sense

Guidelines for care and maintenance are provided by JHB Arts as a courtesy and are for reference only. Duty of care and common sense supersede any and all verbal and/or written instructions provided. These guidelines may not be applicable depending on one or more factors including, but not limited to site conditions, availability and skill of personnel, access to necessary equipment and/or supplies.

### B. Placement of Artwork

Claremont McKenna College
650 Amherst Avenue
Claremont, CA 91711

### C. Materials and Finishes

Cast Glass Bricks:
3,000 custom cast glass bricks in 25 different colors
16 cm x 16cm x 32cm (6 1/4" x 6 1/4" x 12 1/2") each

Sealant:
Dowsil 993 Two-part Whiter Structural Glazing Sealant

## II. General Care and Maintenance Guidelines

### A. Ladders, Scaffolds and Other Equipment Must Never Contact the Artwork

Ladders and other equipment necessary to reach portions of the Artwork must be carefully placed to avoid any contact with the Artwork. Personnel working on the cleaning and inspection of this Artwork must avoid leaning on or supporting themselves using any portion of the Artwork. Articles of clothing and other related materials or devices must never come into contact with the Artwork.

### B. Cleaning

The frequency of the cleaning will be dependent on a number of factors including buildup of dust, guano and air borne particulates.

1. Rinse entire Artwork with low-pressure filtered tap water to remove air borne dust and debris (Image 1)
2. Wash with diluted Orvus paste cleaner mixed with filtered tap water (Image 2)
3. Beginning at the top of the Artwork, soak microfiber mitt (Image 3) in diluted soap water solution and wash surface
4. Do not allow soap mixture to dry on surfaces\
5. Rinse with filtered tap water
6. Allow to air dry
7. Spray microfiber cloth with diluted Isopropyl alcohol and wipe bricks to remove spotting (Image 4)

## III. Final Notes

It is recommended the Artwork be inspected on a weekly basis. Soiling and guano should be removed as needed with filtered water dampened microfiber cloth followed by wiping with Isopropyl alcohol dampened microfiber cloth.

It is recommended biannual cleaning of the entire Artwork be performed.

## IV. Contact Information

Any maintenance beyond the procedures outlined above should be referred to JHB Arts or a qualified conservator. Please feel free to contact us with any questions pertaining to this Artwork.

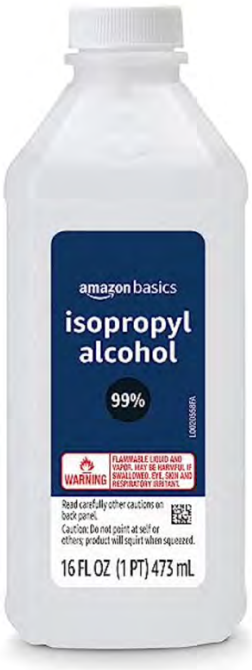
John H. Baker, Owner
JHB Arts
607 Angelus Place
Venice, CA 90291
M. 310.666.9067
E: john@jhbarts.com

Image 1

Image 2

Image 3

Image 4




END OF MANUAL

VIRACON®

800 Park Drive
Owatonna, MN 55060

800.533.2080
viracon.com

# VIRACON'S STANDARD TEN-YEAR LIMITED WARRANTY

Viracon's Standard Ten-Year Limited Warranty ("Limited Warranty") applies to the Viracon products listed below manufactured after the effective date.** The provisions on page 2 are incorporated into Viracon's Limited Warranty.

**TEMPERED AND HEAT STRENGTHENED GLASS**
Viracon warrants its tempered and heat strengthened glass to meet the requirements of ASTM C-1048 **for a period of ten (10) years from the date of manufacture**.

**DIGITALDISTINCTIONS™ CERAMIC INK DIGITAL PRINT, VIRASPAN™ CERAMIC FRIT SILKSCREENED AND SPANDREL GLASS**
Viracon warrants its DigitalDistinctions ceramic ink digital print, Decorative Silkscreened and Spandrel Glass with a Viraspan™ ceramic frit coatings **for a period of ten (10) years from date of manufacture** against defective materials or workmanship which could result in peeling, cracking or deterioration of the ceramic ink or frit under normal conditions.

**HIGH-PERFORMANCE COATED GLASS**
Viracon warrants its high-performance coated glass **for a period of ten (10) years from the date of manufacture** against defective materials or workmanship which could result in peeling, cracking or deterioration in the metallic coating greater than 1/8 inch into the viewing area under normal conditions.

**INSULATING GLASS UNIT (DUAL SEAL UNIT)**
Viracon warrants its dual seal insulating glass **for a period of ten (10) years from date of manufacture** against defective materials or workmanship which result in fogging or moisture residue formation on internal glass surfaces due to failure of the insulating glass seal.

**INSULATING GLASS STRUCTURAL GLAZING**
Viracon warrants that the structural bond between the glass substrates of Viracon insulating glass units will not fail adhesively or cohesively as a result of defective materials or workmanship when installed in accordance with Viracon application recommendations. Viracon's warranty shall be **for a period of ten (10) years from the date of manufacture**. The structural glazing system designer is responsible for design of the structural glazing support system including structural silicone joint dimension (glass to metal support). Viracon assumes no responsibility for adhesive or cohesive failure of structural silicone seals resulting from incompatible structural or weather sealants, incompatible materials (setting blocks/glazing gaskets), improper use or handling, faulty installation or faulty building construction or design.

**INSULATING GLASS UNIT (SLOPED GLAZING)**
Viracon warrants its insulating glass **for a period of ten (10) years from date of manufacture** against defective materials or workmanship which result in fogging or moisture formation on internal glass surfaces due to failure of the insulating glass seal.

**STRUCTURAL GLAZING OF METAL EXTRUSIONS**
Viracon warrants that the structural bond between the aluminum extrusion and glass substrate will not fail adhesively **for a period of ten (10) years from the date of manufacture** as a result of defective materials or workmanship when installed in accordance with Viracon application recommendations. The structural glazing system designer is responsible for the design of the system including the structural silicone joint dimension (glass to extrusion) and the compatibility of any finishes applied to the metal extrusions.

**LAMINATED GLASS AND LAMINATED GLASS SLOPED GLAZING**
Viracon warrants its laminated glass **for a period of ten (10) years from the date of manufacture** against defective materials or workmanship that results in delamination.

**** Viracon's Standard 10-Year Limited Warranty does not cover heat soak tempered glass. Reference Viracon's Heat Soak Tempered Glass Standard Limited Warranty for details.**

## DISCLAIMERS, EXCLUSIONS, LIMITATIONS, AND ADDITIONAL TERMS AND CONDITIONS APPLICABLE TO VIRACON'S LIMITED WARRANTY

In the event that a Viracon product is found and verified by Viracon to be defective under the Limited Warranty, Viracon will replace the product without charge, FOB nearest shipping point to the place of installation or, at Viracon's option, refund the purchase price of the glass. In no event will Viracon's liability exceed the purchase price of the glass. If Viracon elects to replace the defective glass, Viracon will not be liable for any other expenses, including but not limited to, removal of the defective unit, installation of replacement units, any labor, materials, and/or any other damages, including incidental, indirect, special, or consequential damages. Further, the warranty of the replacement glass will be limited to the remainder of the warranty period of the original glass.

Viracon expressly assumes no responsibility for and Viracon's Special Limited Warranty does not cover the following: glass breakage, product failure due to improper usage; product failure due to improper handling, loading, unloading or product storage and length; incompatibility with other glazing or installation materials, including but not limited to, coatings, sealants, gaskets, setting blocks, lubricants, insulation or any other materials; faulty installation or building construction; damage caused by water not attributable to the Viracon product; failure to adhere to Viracon's instructions regarding installation and/or maintenance of the unit (available within Viracon's Glazing Guidelines at www.viracon.com), including written proof of routine maintenance (consult Glass Association of North America Glazing Manual); improper design; errors in provided specifications; scratches or abrasions to the product; abnormal weather conditions; or damage caused by cleaners, solvents, acids, alkalies or any other chemicals used on or around the products. Viracon reserves the right to inspect, in the field, any Viracon product that is alleged to be defective.

The purchaser's exclusive remedy is limited to the legal remedies described in Viracon's Limited Warranty. Viracon will not be liable for any incidental or consequential damages of any kind. Viracon's Limited Warranty will be void in the event that full payment is not received for goods and services within the agreed upon terms of sale. VIRACON MAKES NO OTHER WARRANTY, EITHER EXPRESS OR IMPLIED, REGARDING THE PRODUCT, INCLUDING, BUT NOT LIMITED TO, MERCHANTABILITY OR FITNESS FOR A PARTICULAR PURPOSE. Viracon's Limited Warranty may only be modified upon written approval of Viracon's President or Vice President(s).

Notice of a claim under Viracon's Limited Warranty must be provided to Viracon in writing within 90 days of discovery of the facts giving rise to the claim and should be directed to:

**Viracon Sales Department**
**800 Park Drive, Owatonna, MN 55060**
**Phone: (507) 451-9555**