

Corning: Supplier of Multiple Optical Materials for Telescope Projects

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ABSTRACT

Corning manufactures several optical materials that can be used as reflective and transmissive optics for telescope optical systems. Corning can manufacture these materials in a large range of sizes and configurations. This paper discusses Corning's portfolio of optical materials and their properties, along with Corning's manufacturing capabilities using these materials. Specific examples of optical blanks that Corning has supplied will be discussed.

Keywords: ULE[®], HPFS[®], Optical blank, CTE, index homogeneity, metrology

1. INTRODUCTION

Corning has been manufacturing glass for over 150 years for applications ranging from railroad lanterns to light bulb envelopes. In the mid 1930's, Corning took a huge step toward its astronomical future by casting what was, at the time, the world's largest primary telescope mirror. The 200-inch Hale Telescope primary mirror was cast out of Pyrex borosilicate glass and delivered to Caltech in the spring of 1936.

Since manufacturing the Hale Telescope primary mirror blank, Corning has supplied many mirror blanks for astronomy tools world wide. In the late 1950's, Corning produced the first large fused silica telescope mirror blank, the 0.9-meter blank for the Stratoscope II telescope. This was the first relatively large astronomical telescope having a low expansion mirror blank¹. Throughout the 1960's and 1970's Corning produced many large fused silica blanks for such projects as the 100-inch primary mirror blank for the Las Campanas telescope at the Carnegie Observatory and the 88-inch primary mirror blank for what was then the world highest telescope at the Mauna Kea Observatory. In the mid 1960's, Corning developed the vertical seal process to fabricate even larger fused silica blanks up to 4 meters, including the 2.7-meter McDonald Observatory fused silica primary mirror blank and the ESO 3.6-meter fused silica blank.

In the late 1960's, Corning increased the performance and value of astronomical mirror blanks by introducing Corning Ultra Low Expansion glass material, Corning ULE^{®†}. The industry need for a zero expansion mirror material gave birth to Corning ULE. Because of its nominally zero coefficient of thermal expansion near room temperature and other unique characteristics, ULE glass has been the material of choice for many large astronomical telescopes and space satellite applications since its introduction². One of the first large mirror blanks manufactured from ULE was the 138-inch Italian Observatory primary mirror blank produced using Corning's hex seal process. Since that time, several ULE mirror blanks are made annually by Corning, ranging from less than half a meter up to 8 meters in diameter. Corning has also developed processes to manufacture lightweight mirrors that are greater than 90% lightweight.

Today both HPFS^{®††} fused silica and ULE are manufactured at the Corning Canton Plant in northern New York State. The plant was opened in 1966 specifically for the purpose of manufacturing fused silica and ULE mirror blanks.

[†] ULE[®] is a registered trademark of Corning Incorporated. ULE is available as Corning Code 7972.

^{††} HPFS[®] is a registered trademark of Corning Incorporated. HPFS is available as Corning Code 7980.

Currently Corning has the ability to manufacture mirror blanks and other optical components for astronomy applications using a variety of materials ranging from exotic glasses to diamond turned metallic materials. Corning's fabrication processes have produced solid blanks up to 8 meters in diameter and lightweight mirror blanks up to 2.5 meters in diameter. Corning can manufacture lightweight ULE mirrors using a host of processes ranging from front and back plates frit bonded or fusion sealed to lightweight core sections, to open backed CNC machined blanks. Fused silica is still used for any applications where high quality transmissive optics are required.

2. CORNING LOW EXPANSION MATERIAL

2.1 Corning Code 7972 ULE

Corning ULE boules, manufactured at the Corning, Canton Plant, are produced in a refractory forming furnace using a flame hydrolysis process where silica and titania chemical precursors are introduced into a gas/oxygen flame. Silicon dioxide-titanium dioxide soot is deposited into a rotating furnace cup and consolidated into amorphous ULE glass. After ULE boules are formed, they are removed from the forming furnace and fine annealed in separate annealing ovens. This fine anneal process is specific to ULE glass. The anneal cycle relaxes the ULE glass into its most internally stress free state. Any residual stress remaining in the ULE boule is a direct result of slight compositional differences found in the boule.

After ULE boules are annealed, refractory material is ground from the outside of the boule. After this grinding process, standard ULE boules are approximately 1.47 meters diameter and 150 mm thick. ULE boules are optimized for Coefficient of Thermal Expansion (CTE) uniformity and inclusion quality in order to meet today's demanding mirror requirements. Corning's tight process control results in boules that exhibit very good CTE uniformity. Boules are produced in a rotating furnace that inherently results in very good radial symmetry, thus very good radial CTE uniformity. ULE boules are also manufactured and characterized in a way to assure repeatable quality. Continual monitoring of the glass forming process and carefully controlled input results in predictable (quality) output.

After the fine anneal is performed and the boule is fine ground to remove the refractory material, the boule CTE characterization takes place. The CTE is a key property for mirror blanks that operate in environments having thermal gradients. Material with a zero, or near-zero, CTE over the temperature range of operation will exhibit minimal dimensional changes. Corning uses a non-destructive ultrasonic velocity method to characterize the CTE of ULE. Ultrasonic transit time is measured through the depth of the boule, from top surface to bottom surface. The ultrasonic transit time and a very accurate measurement of boule thickness are used to determine ultrasonic velocity. The titania concentration impacts the density and Young's modulus of the glass which dictate the ultrasonic velocity through the material. Because ultrasonic velocity and expansivity both correlate linearly with titania content, simple measurement of ultrasonic transit time through a given thickness of ULE yields the CTE of the glass. By determining how the velocity varies radially across the boule and axially through the thickness using rigorously defined and controlled procedures, each ULE boule is fully characterized for its CTE distribution. Figure 1 depicts how the CTE of a boule is typically characterized. This non-destructive characterization enables the telescope designer to use actual CTE data for the blanks that are provided to predict mirror performance.

A unique characteristic of ULE is that when a difference in CTE exists between any two pieces of ULE, the difference is constant, independent of temperature, permitting differential measurements of the room temperature CTE to apply to all temperatures between 78 K and 1198 K³. Since all ULE Coefficient of Thermal Expansion (CTE) curves are parallel in this temperature region, a simple measurement of CTE at room temperature is all that is needed to establish the entire instantaneous thermal expansion coefficient curve.

ULE boules are also inspected for Inclusions. Index matching oil, high intensity light and a depth measuring microscope are used to locate and measure inclusions that are larger than 0.12mm (0.005"). The size and location of the inclusions are mapped for each boule. The inclusion inspection data is used to select critical volumes in mirror blanks and components.

RADIAL & AXIAL CTE CHARACTERIZATION

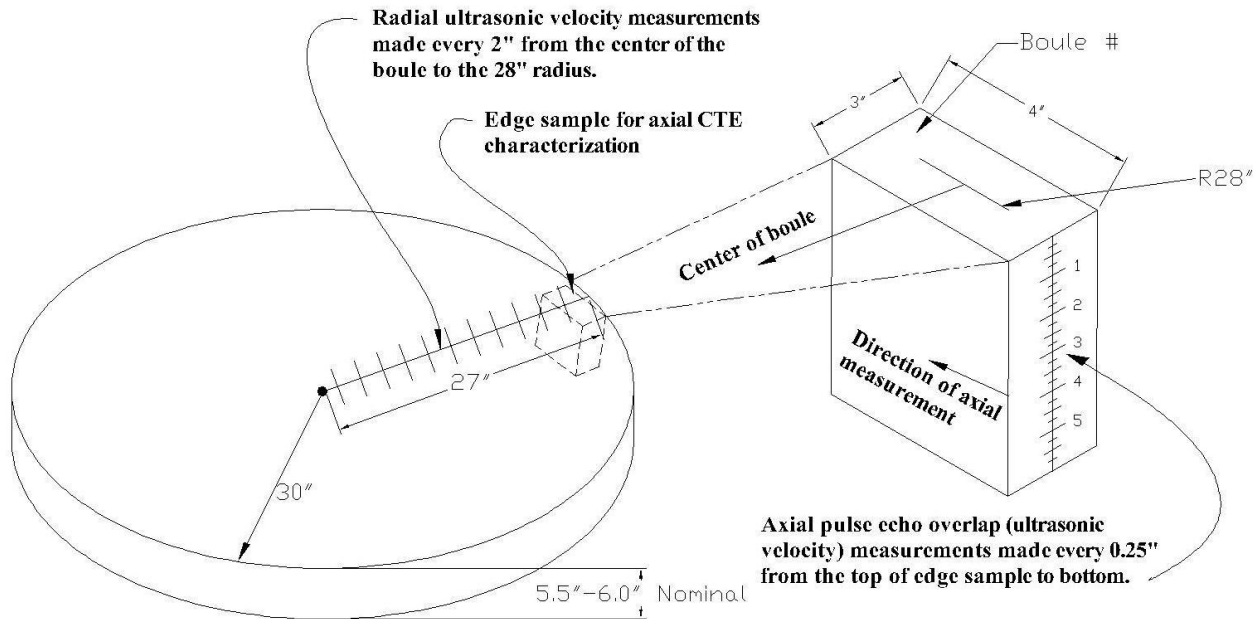


Figure 1

Table 1 below indicates reference values for ULE physical properties as determined as part of the recent 7972 qualification efforts. A full set of material properties and specifications can be found in the Corning 7972 ULE product catalog.

TABLE 1
Corning Code 7972 ULE Reference Physical Properties

Mean CTE (from 5°C to 35°)	0 +/- 30 ppb/K
Stress Optical Coefficient	4.15 (nm/cm)/(kg/cm ³)
Density	2.20 g/cm ³
Young's Modulus	67.6 GPa
Poisson's Ratio	0.17
Knoop Hardness	460 kg/mm ²

2.2 Corning TSG Material

Corning Titania Silicate Glass (TSG) was introduced recently as a slightly lower grade material having a less restrictive requirement on mean CTE than Corning ULE. TSG is manufactured with the same process as ULE. As described above, refractory furnaces are used where silica and titania precursors are introduced to gas oxygen burners. Soot is deposited in the furnace and the material consolidates into Corning TSG.

TSG is an ideal material where absolute CTE requirements are less stringent. The vital difference between Corning ULE and Corning TSG is the allowable absolute CTE. ULE is defined as material with a mean absolute CTE of 0

+/-30 ppb/°C over the temperature range of 5°C to 35°C, whereas TSG is defined as material with a mean absolute CTE of 0 +/-100 ppb/°C over the same temperature range. In many applications the extremely narrow absolute CTE requirement of ULE is not essential and TSG material may be suitable.

The CTE of TSG can be characterized in the same way, using the same equipment, as the CTE of ULE is characterized. The uniformity of TSG can also be similar to that of ULE, but catalog grades are offered which allow somewhat higher variation, creating a cost savings for the customer. Table 2 below indicates reference values for TSG physical properties

TABLE 2
Corning TSG Reference Physical Properties

Mean CTE (from 5°C to 35°)	0 +/- 100 ppb/K
Stress Optical Coefficient	4.15 (nm/cm)/(kg/cm ³)
Density	2.20 g/cm ³
Young's Modulus	67.6 GPa
Poisson's Ratio	0.17
Knoop Hardness	460 kg/mm ²

3. CORNING CODE 7980 HPFS MATERIAL

Corning HPFS Fused Silica is a high purity synthetic amorphous silicon dioxide glass manufactured by flame hydrolysis in the Corning Canton Plant. HPFS is the material of choice for large optic designs that require exceptional transmission in the UV and visible range, high index homogeneity, low birefringence, and low CTE.

HPFS is manufactured in a process very similar to ULE with the exception that HPFS does not include a titania precursor in the deposition phase. The resulting HPFS boule size after refractory material is removed is typically 1.5-meter diameter and 125-200mm thick. Like ULE, HPFS is annealed to remove internal stress, resulting in very low birefringence. After the fine anneal the boule is ready to be allocated for use and the remaining boule processing is product dependent.

For large blanks requiring index homogeneity certification, the boule is processed for Polished Homogeneity (PHOM) measurement. The boule is prepared for measurement by polishing the faces to a low flatness specification and a prescribed amount of wedge. The wedge is required so that both surfaces can be measured and surface errors can be removed from the measurement. Corning utilizes a Zygo phase measuring interferometer to make a series of 610 mm aperture measurements of the boule; these measurements are then used to identify the optimal location for blank extraction according to customer requirements. Nominally all measurements within a boule are less than 4 ppm Δn. However, boules will yield 610-760 mm diameter blanks that meet 3 ppm down to 1.5ppm Δn. In most cases the boule measurements are used to certify the index homogeneity of the extracted blank. However, Corning can also re-measure individual blanks by utilizing either the PHOM technique or “oil on flat” technology.

Table 3 lists reference properties for Corning 7980 HPFS. A full set of specifications and grades available can be found in the Corning 7980 HPFS catalog.

TABLE 3
Corning Code 7980 HPFS Reference Physical Properties

Mean CTE (from 5°C to 35°)	520 ppb/K
Density	2.20 g/cm ³
Young's Modulus	72.7 GPa
Modulus of Rupture	52.4 MPa

Bulk Modulus	35.4 GPa
Poisson's Ratio	0.16
Knoop Hardness	522 kg/mm ²
Birefringence	≤ 1nm/cm

Corning Code 7980 HPFS material has been used in several astronomy applications other than the reflective substrates mentioned previously made in the 1960's and 1970's. More recently, this material has been used as transmissive optics in such programs as the LIGO interferometer, LBT 40" correctors, Keck upgrade prisms, Smithsonian Hectochelle multi-purpose spectrograph, and Pan-STARRS optics.

4. CORNING PROCESSES FOR MANUFACTURING LARGER BLANKS

For HPFS and ULE blanks that have dimensional requirements beyond the standard boule size, Corning offers high temperature post-forming options including high temperature stack sealing, sagging (slumping), and flow-outs.

High Temperature Stack Sealing is used to achieve additional thickness by sealing multiple boules on top of each other.

High Temperature Flow-outs are used to manufacture blanks that require a diameter larger than a formed boule. Flow-outs require heating a boule to a viscous state through a process that yields a much larger diameter blank of similar volume to the parent boule. Flow outs can yield blanks up to 2.5 meters in diameter.

High Temperature Sagging is a process used when a design calls for a meniscus shaped blank (concave/convex surfaces). A sagged blank is formed by heating a plano-plano blank to a softened state and allowing it to slump or "sag" onto a contoured refractory form yielding a near net shape. Fine grinding is typically performed on the blank after sagging to yield the required part. Figure 2 illustrates a final blank within the near net shaped sagged blank.

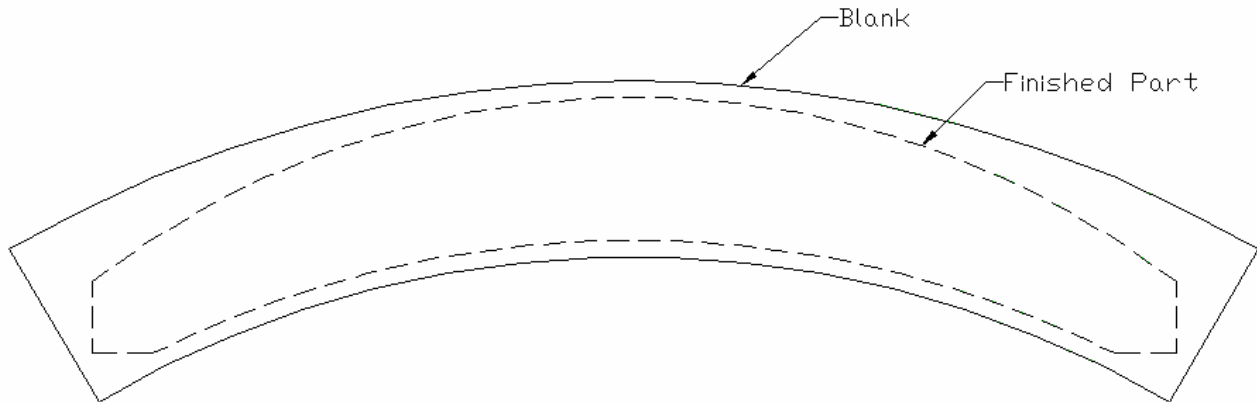


Figure 2

Figure 3 below shows a fused silica blank in the sagging furnace prior to sagging and after sagging.

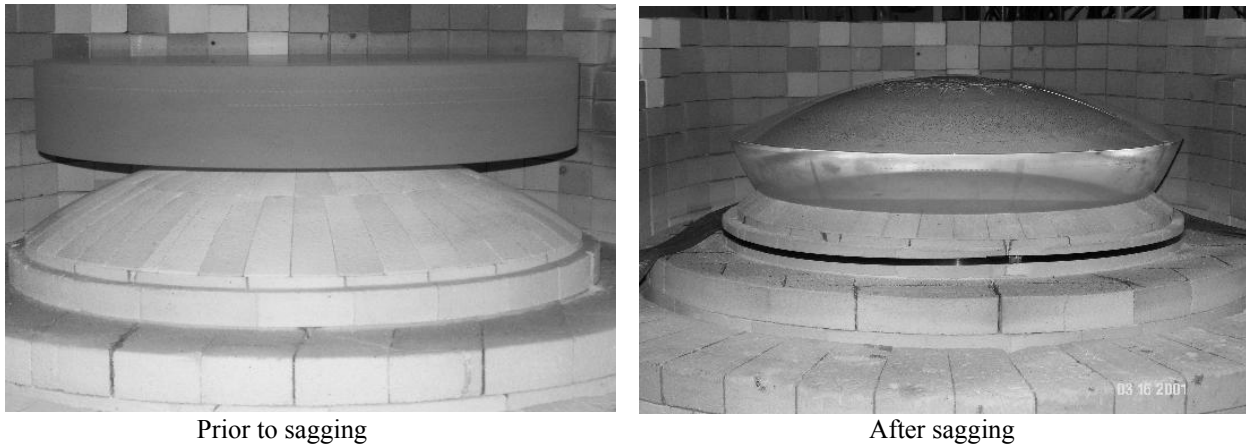


Figure 3

High Temperature vertical Sealing, also known as hex sealing, is used to achieve diameters larger than 2.5 meters. This process was originally used to manufacture large fused silica reflective optics and is now used primarily for large ULE reflective optics. The vertical seal process typically uses hex shaped segments that are precision ground to fit together with very tight tolerances. After the segments are manufactured they are assembled in a large 8-meter sealing furnace. The turntable on this furnace can also be converted to a rotating grinding table to grind blanks up to 8 meters in diameter. The segments are heated to the point which the material becomes viscous and the segments seal to one another creating a large monolithic blank. This same furnace can also be used to sag the large blanks and anneal the blanks after all heat treatments have been performed. The large 8-meter blanks for the Subaru and Gemini telescopes were manufactured in this furnace using the hex seal process as where the 4-meter SOAR (Southern Observatory for Astronomical Research) and DCT (Discovery Channel Telescope) blanks. Figure 4 shows an example of hex segments prior to sealing and after sealing.

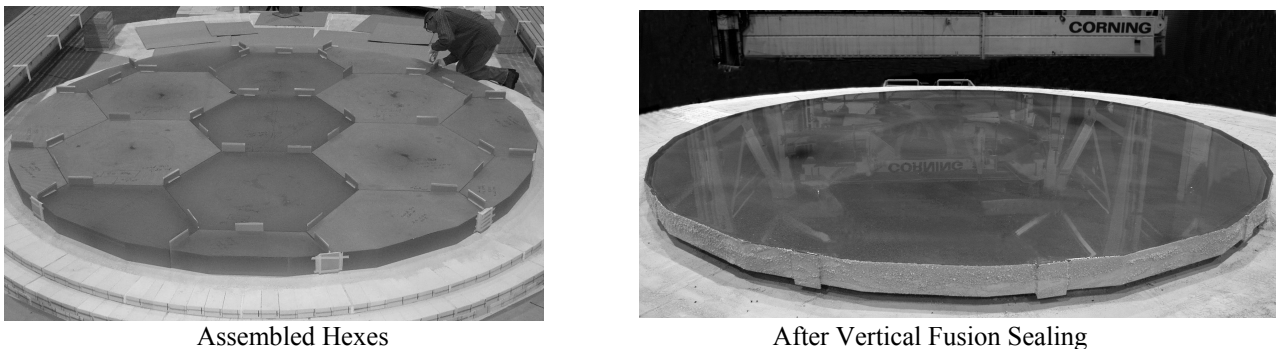


Figure 4

High temperature post-forming processes can also be used in combination depending on the final part design requirements. A blank that is initially flowed out can then be sagged to a meniscus shape to yield a large meniscus greater than 1.5 meters in diameter. The flow-out and sagging processes are volume dependent, the volume of the final part is dependent on the volume of glass used. In the case of HPFS, application of the stack sealing process needs to be carefully evaluated due to the potential for distortion of transmitted light waves beyond the specifications of the finished optic and for tiny inclusions in the seal plane between boules.

5. CORNING MANUFACTURING FLEXIBILITY

As a manufacturer of large blanks Corning has the equipment, process knowledge and capability to fabricate a variety of optical materials. The Corning Canton Plant is known not only as a manufacturer of high quality glass materials but also as a world class optical blank fabrication facility.

The equipment used to fabricate ULE and fused silica blanks can also be used to fabricate other materials. For example, Corning has experience machining glass-ceramic blanks up to 3.5-meters in diameter. Stock removal rates and tool speeds and feeds may be adjusted to accommodate the specific material being fabricated. Corning also has experience acid etching glass ceramic materials.

Corning has also processed and fabricated several Conformal Window Blanks for the AirBorne Laser (ABL) program. The ABL Conformal Window requires a material highly transparent at 1.315 micrometers. Infrasil[®] 302, manufactured by Heraeus Quarzglas, is the only material currently available with the required low absorption at 1.31 micrometers that could be produced in a large enough quantity to make the window from a single piece. Corning's ability to re-form the Heraeus glass into sagged blanks utilizing the stack seal, flow-out and sagging processes enabled the Infrasil glass to become a highly curved optic slightly larger than 1 meter diameter⁴. The high temperature process details were refined based on the viscosity of the Infrasil material; however, Corning was able to process this material into a near net shape using the heat treatments previously described. After the near net shape was achieved, Corning used CNC controlled grinding equipment to grind the blank into a highly curved thin meniscus blank.

Corning has also used Infrasil 302 material to produce optics for the VISTA projects, similar to the ABL work described above. Corning started with 24" Infrasil ingots and used the flow-out process to produce 40" windows for the VISTA IR spectrograph. This is yet another example of Corning leveraging its capabilities and equipment to process material manufactured by others.

6. ADDITIONAL CORNING CAPABILITIES

Corning also operates facilities in Fairport, New York and Keene, New Hampshire that have the capability to process materials for astronomy applications. The Corning Tropel facility in Fairport is a world leader in fabricating precision optics and lens assemblies. The capabilities of Corning Tropel include optical design, mechanical packaging, opto-mechanical thermal and structural analysis, and thin film coating design. Corning Tropel can produce flats, spheres, aspheres and diffractive lens elements. Tropel has extensive metrology capabilities with over 40 interferometers and advanced metrology tools.

Corning Net Optics in Keene, New Hampshire brings diamond turning capabilities to the Corning portfolio. Net Optics is one of the largest diamond turning facilities in the world, with 16 diamond turning machines to fabricate reflective elements and subassemblies up to 880 mm (35") in diameter. Net Optics has extensive metrology capabilities and in-house coating capability including numerous vacuum coating chambers for all types of reflective and transmissive coatings, along with full UV-VIS-IR reflectance measurement capability. A state of the art in-house electroless nickel plating facility is also available for applications requiring nickel plated optics.

4. SUMMARY

This paper has described Corning's optical material manufacturing and fabrication capabilities for optics that serve the astronomy market. Corning has a rich history of manufacturing high quality materials for astronomy applications starting in the 1930's and maturing to today's ULE and HPFS materials. Corning has a host of fabrication equipment and processes allowing Corning to seal, flow-out, sag and grind blanks to near net shapes up to 8 meters in diameter.

Corning also has the resources and experience to fabricate blanks using materials that are not manufactured at Corning. With the addition of Corning Tropel and Corning Net Optics to the Corning family the ability to serve all aspects of the astronomy market has been greatly enhanced.

Corning offers the ability to purchase a wide range of your optical blank needs from a single company. This ability allows the customer to leverage their buying power with a single company to save time and money in their optical materials procurement. Corning can offer a variety of competitive solutions when a total picture of the optical needs of a project are provided. The individual locations within Corning can work together to offer a customer the best possible resolution to their optics challenges at the best possible pricing and overall service.

ACKNOWLEDGEMENTS

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