Improved Production of Large and Multi-Directional Homogeneous Optical Glass: SCHOTT N-BK7® for Challenging Applications

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Abstract. In many applications, the spatial refractive index variation – called homogeneity – within a measurement aperture either in one or two directions is important. Typical application examples are prisms in ultra-precision metrology with stability in multiple directions. Large lenses are used in artificial laser guide star systems for atmospheric correction in large telescopes. The challenge of enabling highest refractive index homogeneities requires tight control of all production steps from melting to hot forming and fine annealing. Large optical formats can be produced as singular castings in moulds up to 1.2 m in diameter and 250 mm thickness. Smaller formats are available as blocks produced in dimensions of approx. 250 x 250 x 180 mm^3. A more economic and ecologic way is the production of continuous strips of glass up to approx. 500 mm width and 120 mm thickness. Recently SCHOTT has improved the homogeneity of these continuously produced jumbo strips significantly. Now homogeneity of up to H4 quality (2 ppm index maximum variation) can be provided on apertures up to approx. 900 mm x 500 mm. This paper gives an insight overview on the latest results and current state of this topic at the optical glass manufacturer SCHOTT.

1 Homogeneity of the refractive index

The absolute refractive index of optical glass is measured with refractometers at SCHOTT. The efficient V-block refractometer provides index control up to the fifth digit, while the spectral goniometer "Ultraviolet to infrared Refractive Index measurement System" (URIS) ensures reliable measurement over a broad spectral range up the sixth digit[1].

Whereas homogeneity is defined as the peak to valley variation of the refractive index at a certain aperture. The measurement is carried out with an optical interferometer. To exclude surface effects from the measurement either oil-on-plate or PHom method are used. The obtained wavefront deformation is a function of the lateral variation of the refractive index integrated over the sample thickness[2].

Corresponding to the variation of the index within the defined aperture the maximum and minimum value define the so-called peak-to-valley (PV) in ppm. Table 1 provides an overview of the homogeneity grades at SCHOTT according to the ISO-norm. The homogeneity grades can be applied in multiple directions for 2D or 3D homogeneity, respectively, depending on customer needs. Homogeneity is crucial for optical applications with highest performance and tightest tolerances where a low wavefront deformation is mandatory to ensure the proper functionality of the device.

Since homogeneity scales with size/aperture it is important to specify homogeneity properly to the requirements of the application. Typical fields of application are: large lenses in artificial laser guide star systems of extremely large telescopes for atmospheric correction, ultra precision metrology with homogeneity requirements in multi directions for IC lithography, high power laser fusion facilities, or interferometer industry.

Table 1. Homogeneity grades of SCHOTT optical glass according to ISO-norm [3, 4]

SCHOTT homogeneity class indicator	NEW ISO 12123:2018 and ISO 10110-18:2018		OLD ISO 10110-4:1997	General applicable for
	Class indicator	tolerance limits Δn [10^{-6} or ppm]	tolerance limits Δn (+/- notation) [10^{-6} or ppm]	
	NH100	100	± 50	Common application sizes
H1	NH040	40	± 20	
H2	NH010	10	± 5	Partial volumes of the raw glass
H3	NH004	4	± 2	
H4	NH002	2	± 1	Not in all dimensions and not for all glass types
H5	NH001	1	± 0.5	

At SCHOTT we currently run three different interferometers for homogeneity measurements. For large blank and castings a Zygo Verifire MST with 600 mm (24 inch) aperture located in Duryea (USA) and a Zeiss 100 Direct with and 500 mm aperture, located in Mainz (Germany) are available. For larger dimensions multiple

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measurements of the given aperture are carried out and stitched via software to the full extent of the specimen, as shown in Figure 1. Additionally, SCHOTT operates another Zeiss Direct 100 interferometer with 300 mm aperture in Mainz (Germany).

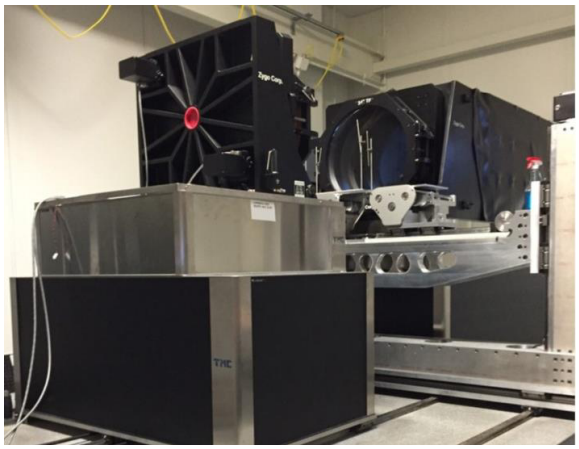

Fig. 1. Interferometer Zygo Verifire with 600 mm aperture at SCHOTT in Duryea with large casting of SCHOTT N-BK7®.

2 Typical formats of SCHOTT N-BK7®

The optical glass SCHOTT N-BK7® with high homogeneity is available in different formats and geometries of pressings, blocks, jumbo strips, and castings within a broad range of weights from approx. 0.1 – 700 kg and sizes from cm to m, see Figure 2. Beside the format described above individual format are possible.

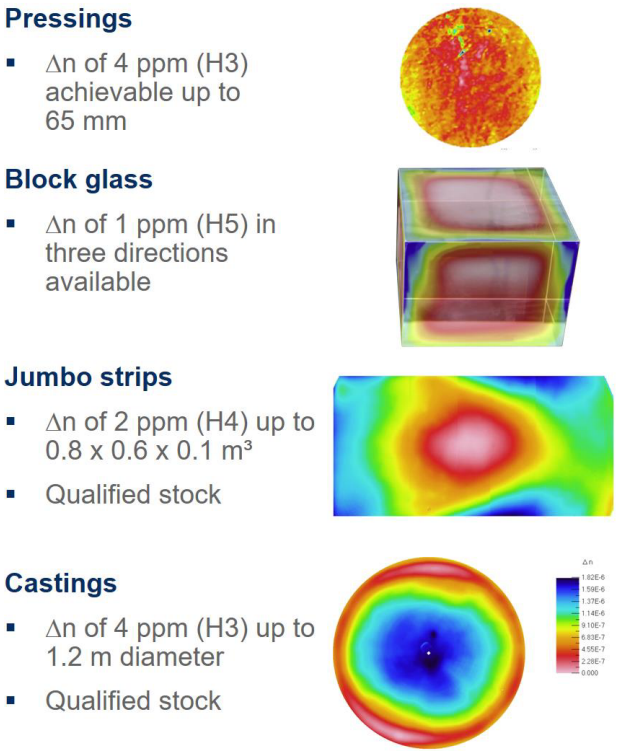

Fig. 2. Overview of different formats and geometries of SCHOTT N-BK7® with typical high homogeneity quality grades in false color code of interferometric measurement. Pressings are available up to 4 ppm (H3), while blocks and jumbo strips can serve up to 1 ppm (H5) and 2 ppm (H4), respectively, even in multiple direction. Large castings achieve highly symmetric homogeneity distributions up to 4 ppm (H3) on a 1-m-scale or even better with reduced diameter.

3 Improved quality of SCHOTT N-BK7®

The production of optical glass with its tight tolerances in the optical position, low stress birefringence and inner quality is extremely challenging. Nevertheless, for optical glass of high homogeneity the requirements are one to two orders of magnitude tighter specified.

To avoid inefficient pick and choose for high homogeneity optical glass affecting reliability and delivery times it was inevitable to re-evaluate each step in the manufacturing process and identify potential levers on homogeneity: raw materials, melting process, refiner, hot forming, as well as coarse annealing and fine annealing. With an interdisciplinary team from SCHOTT it was possible to identify the most relevant levers and to adjust accurate process settings yielding high homogeneity of 2 ppm even on large apertures in the regime of 800 x 400 mm^2 as depicted in Figure 3.

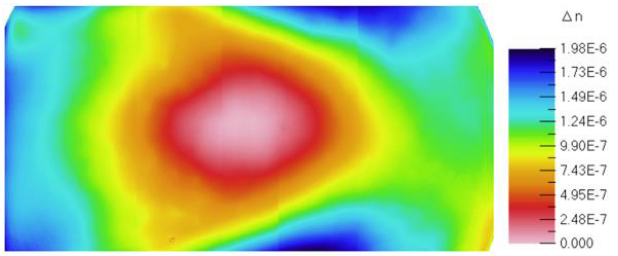

Fig. 3. Representative interferometric measurement of the refractive index of a SCHOTT N-BK7® jumbo strip with an aperture of approx. 800 x 400 mm^2 in false color code. The low peak-to-valley index variation achieves 1.98 ppm (H4).

Acknowledgemets

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References

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