Large Lenses and Filters for ELTs:
Challenges and Opportunities for SCHOTT

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Abstract: For the future several extremely large telescope (ELT) projects with primary mirror diameters ranging from 25 m to 100 m are in discussion. The required mirror segments are in the focus of attention of the involved designers. Nevertheless, during the design of an ELT, of large wide field telescopes and of the corresponding instruments one should not forget about the challenging requirements of other optical elements. Especially the dimensions of the required glass blanks for correction optics, spectrometers and within the camera systems will increase significantly. In addition large optical elements will be needed during the testing of mirror segments. Although meter class optical glass blanks have been produced in the past, the main focus of the optical industry is mass production of tiny lenses for consumer applications, but not a production of filters and lenses in the requested dimensions and qualities. So the availability of huge optical components may be a bottleneck for extremely large telescopes and also for wide-field observatories. It is the intension of this paper to call attention to this potential critical path for large future astronomical projects and to discuss the status at SCHOTT and the development needs for huge lenses and large filters.

Keywords: Astronomy, Extremely Large Telescopes, optical glass, Zerodur, filters, lenses

1. INTRODUCTION

Two of the current trends in astronomy are extremely large telescopes (ELTs) and large wide field telescopes (see table 1). For the planned wide field observatories monolithic primary mirrors with diameters of 1.8 m to 8.4 m are considered. The ELT´s are even larger: At present several ELT projects are in discussion, which will use huge primary mirror diameters ranging from 25 m to 100 m. Here segmentation of the main mirror is unavoidable and an effective mass production of mirror segments will be an key element for the success of these projects. Therefore the primary mirrors are in the focus of attention of the involved designers. From SCHOTT´s point of view the quality and the dimensions of ZERODUR mirror blanks for segmented telescopes are present days work, no major technical development is needed here. Also SCHOTT recently tripled its production capacity for the zero-expansion glass ceramic material ZERODUR and is now well prepared for this challenge [1].

Table 1: Listing of future telescopes, which are discussed, planned or in construction

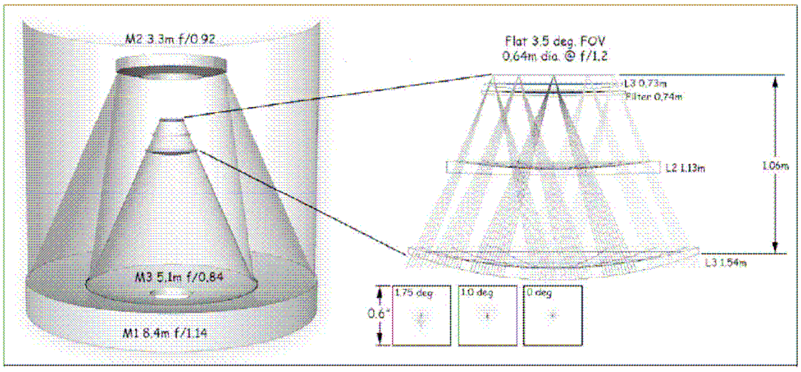
Type of Telescope	**Project name**	**M1 diameter**
Wide field telescopes	VISTA - Visible and Infrared Survey Telescope for Astronomy	4.1 m
	PanSTARRS - Panoramic Survey Telescope and Rapid Response System	4 x 1.84 m
	DCT – Discovery Channel Telescope	4.2 m
	SST – Space Surveillance Telescope	3.6 m
	LSST – Large Synoptic Survey Telescope	8.4 m
Extremely Large Telescopes	GMT – Giant Magellan Telesope	25 m
	TMT – Thirty Meter Telescope	30 m
	OWL – Overwhelmingly Large Telescope	100 m
	EURO50 – European 50 m Telescope	50 m
	JELT – Japanese Extremely Large Telescope	30 m
	CFGT – Chinese Future Giant Telescope	30 m

Nevertheless, during the design of ELT´s and also for large wide field telescopes one should not forget about the requirements of other large optical elements. These components are also challenging and may be even more critical than the primary mirror. Especially the dimensions of the required glass blanks for correction lenses, spectroscopic instruments and for the camera systems will increase significantly for future telescopes. Such telescopes need downstream refractive optics like atmospheric dispersion correctors, colour correctors and beam shapers. In addition several large optical elements will be used during the testing of large mirrors and mirror segments.

2. LARGE TELESCOPES NEEDS LARGE OPTICAL COMPONENTS

At several positions of the discussed future telescopes large diffractive elements are considered. Also in the corresponding scientific instruments large windows, lenses and also prisms are under consideration. During testing of telescope components in the optical workshop elements like test matrices, Hindle spheres, and null lenses will be needed. Usually the following types of glasses are considered for these applications: N-BK7, LLF-1, LLF-6, F5, but also material like CaF_2 and fused silica (SiO_2). Thereby typical lens diameters ranges from about 1.0 m up to 1.7 m.

A detailed specification of the glass material is not available, but probably extremely homogeneous glasses with high transmittance over a broad spectral range in large dimensions are needed. Depending on the position within the telescope, imperfections like bubbles and solid inclusions may not be acceptable. These are challenging requirements for a glass manufacturer, especially as large sizes and excellent internal material qualities have to be fulfilled at the same time. At the example of the LSST telescope baseline design[2,3] we want to demonstrate the importance of a supply chain management. For this wide field telescope probably the upper limit of lens dimensions is chosen. The availability of large lens blanks, especially with the assumed high homogeneity may be a bottleneck. The design considers several large lenses as integral parts of the telescope, thereby the largest lens is designed with a diameter of 1.54 m (see figure 1).



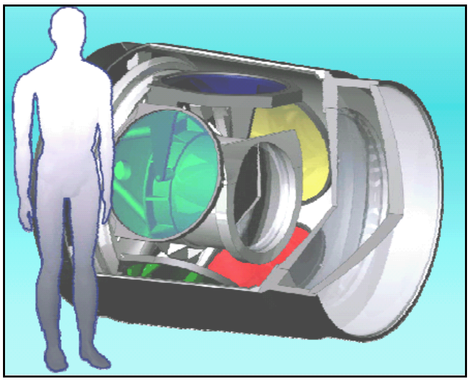


Figure 1: The optical layout of the 8.4m LSST baseline design (left).
Figure 2: A sectional view of the camera concept for the LSST baseline design (right)

The different future telescopes will also need large filters. Within the design of the LSST telescope several huge filters of diameter 740 mm (figure 1, figure 2) are foreseen. The PanSTARRS telescope considers some “smaller” filters of diameter 450 mm. Common bandpass filters cover the whole spectrum (U V B K Z I), thereby several different filter combinations are used (Bessell, Johnson, SOAR, SLOAN).

There are two principal options for the production of these filters: The filter characteristic can be produced by interference coatings or by absorbing glasses. During the coating process the production of large homogeneous coatings and of defect free coatings is challenging . Also one has to deal with the angular dependence of these filters. The classical filtering is done by combinations of absorbing filter glasses. The typical individual filter glass thickness is 1 mm to 4 mm, for a complete filter set up to 11 different glass types are employed.

The filter specifications should consider filter homogeneity, wing suppression, cryogenic behaviour , the allowed content of bubbles and solid inclusions, geometrical tolerances and the filter environment during application. Thereby the stability against global and local shift of bandpass with application temperature may be an additional (and challenging) requirement. A feasible solution are colour glass filters with additional interference coatings, which are needed for sharp filter edges. There are also some first ideas of curved filters, following a curved focal plane. These requirements would be even more challenging. In all cases the production of the required filters is critical and the designer should contact the filter potential suppliers at an early stage.

3. STATUS OF PRODUCTION CAPACITY AT SCHOTT

SCHOTT has been a worldwide leading manufacturer of optical glass for over 120 years. Our latest glass catalogue includes more than 100 glass types [4], which cover our customers' broad range of applications with a large number of different properties. We supply SCHOTT optical glass for rapidly growing consumer markets as well as for high-tech industrial optics markets. SCHOTT has production capacity for various optical glasses, filter glasses and also for fused silica and calcium fluoride. Although large optical glass blanks have been produced in the past [5], at present the main focus of the glass industry is mass production of tiny lenses for consumer applications. Therefore the present product range does not include filters and lenses in huge dimensions and extreme qualities, as requested by the astronomical community. So the availability of the initial glass material for large optical components may be a bottleneck for ELT´s and also for wide-field observatories.

3.1 Production of large lenses

SCHOTT operates different facilities for melting and casting depending on the glass types, the size of a single piece and the number of pieces within a series. The most common melting technique for optical glass is the continuous melting. The melting and casting takes place continuously at the same time in different sections of the tank. The flow rate of glass material during casting is relatively low. Typical products made by this method are 30 cm blocks of optical glass (figure 3). For large pieces the glass flow in a continuous melting tank is not sufficient to fill moulds within reasonable times where one can keep the environment adequately constant, which limits the achievable homogeneity. Optical blanks with diameters larger than 1 m have to be produced in discontinuous melting tanks. The difference to the continuous melting tank is that all process steps from melting to casting are performed time after time in the same place. With a discontinuous tank a large amount of molten glass can be cast in a very short time, which is helpful to prevent in-homogeneities.

Optical glasses comprises a wide variety of chemical compositions. The most common optical glasses that have be produced in large dimensions above 1 m are N-BK7 and F2. Flint glasses have been produced as radiation shielding glass block with dimensions up to 1500x1000x200 mm (Figure 4). At SCHOTT N-BK7 was produced in the past in diameters up to 1600 mm. Figure 5 shows a N-BK7 boules with diameters of 900 mm and a thickness of 400 mm. However, there are also glass types, where it is very difficult to produce them as glasses. Without special precautions they would crystallize completely. Such challenging glass types produced in comparatively small platinum tanks or pots. With special effort one may produce sizes up to about 300 mm diameter. Recent papers [6,7] gave information about the feasibility of large glass blanks and recommendations how to specify the quality, while balancing the requirements of the application on one side and the conditions of the production and for quality inspection on the other side.

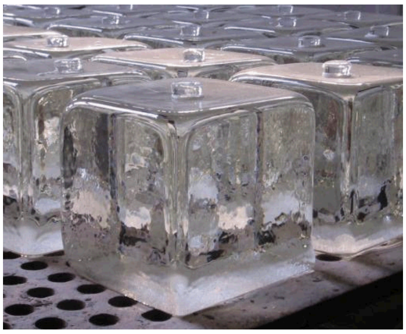


Fig. 3: N-BK7 block glass (left) Fig. 4: Casting of radiation shielding windows (middle) Fig. 5: Large N-BK 7 boules (right)

As large optical glass blanks are usually not available in stock, a critical point may be the overall production lead time. It should be mentioned here that many glasses - except glasses with a high tendency for crystallization - can be reshaped using slumping technique. The glass will placed into a larger mould and heated up to temperatures were the viscosity is low enough so that the glass can slowly flow into the new mould. In general this process does not affect the quality of the glass. For glass blanks in large dimensions the annealing and slumping times increase significantly. Additionally not all glass types can be produced in big sizes and excellent quality at the same time. If large optical glass blank were specified, the designer should choose the tolerances very carefully. There is the risk that tight quality demands lead to an extremely long lead time – or even to a “not feasible" answer from the glass manufacturer. It is therefore important to know the impact of the specification on the realization of large optical glass blanks – and to contact the supplier at an early state.

3.2 Lenses made of ZERODUR ?

Also testing of the individual ELT mirror segments will result in new technical challenges. Due to the long focal lengths the use of a test tower during polishing may be not economic. For the quality assurance of the polishing process sometimes matrix lenses are used alternatively. The requirements for these large matrix lenses are challenging. The glass material needs a high internal transmission at 632 nm and is requested in the dimensions of the mirror segment itself – with some surplus and a corresponding large thickness. In addition a high homogeneity of refractive index, a low bubble content and a low thermal expansion would be helpful. ZERODUR has been used to produce such lenses, using this well-known mirror substrate material in transmission. As it is produced similar to optical glass, selected ZERODUR blanks exhibit the requested excellent internal quality. At figure 6 a raw blank of a dia. 1.33 m ZERODUR testing lens is shown, which was used to test the convex secondary Be-mirror of the 11 m GTC-telescope. The concave surface matches the convex shape of the mirror to be tested and the aspherical convex surface of the matrix lens serves for the interferometer beam shaping.

For future telescopes with even larger dimensions a problem regarding the availability of matrix lenses may occur: Huge optical glasses are not (easily) available and due to their high thermal expansion it may be difficult to reach thermal equilibrium. On the other hand large and therefore also thick ZERODUR lenses have a reduced transmittance due to scattering at the micro-crystals. To overcome this bottleneck the use of glassy ZERODUR has been proposed previously for this application [8,9]. This glassy material is a poor optical glass for usual optical applications, but has a much higher transmission than ZERODUR at 632 nm. Due to the low – but non-zero – thermal expansion of around $3 * 10^{-6}$/K it may be used for matrix lenses. As an intermediate state within the production glassy ZERODUR is usually available in large dimensions. Nevertheless, also some development is needed here, especially to deal with stress birefringence by fine annealing.

3.3 Production of large filters

Coloured and filter glasses are often applied due to their selective absorption in the visible wavelength range. The filters appear to be coloured if their filter effect lies within the visible light spectrum. Worldwide there is only a very limited number of filter glass production companies. Thereby SCHOTT is one of the leading filter glass manufacturers with a product range equalled by no other manufacturer. Various sizes, shapes and qualities can by provided on request. Also R&D expertise is available to find the optimal solution to customers filter problems. SCHOTT is probably the only available source for the challenging huge filter glasses as probably needed for future telescopes.

Within a global enterprise like SCHOTT a production at several plants have to be coordinated. At the SCHOTT plant in Gruenenplan GG, OG, RG filters are produced in clay pot melts. Typically an amount of 600 kg of each of these filter glass is cast once a year. The next melting campaign is scheduled for November 2005.

Usual filter sizes are 50 x 50 mm. At SCHOTT even larger formats of filter plate sizes are usually available in stock and covers up to 165 x 165 x 4.5 mm for most filter types. The maximum dimensions of raw filter glasses for GG, OG, RG filters are 900 x 900 x 7 mm (figure 7). Please note that the melting process is not optimised for homogeneity here. Also quality assurance of (absorbing) filter glasses is still a challenge and not solved for huge dimensions.

BG glass types are difficult to be produced in large dimensions. They are produced in strips of 165 mm width at the SCHOTT plant in Mainz. Instead of the initially requested 1 m sized filters SCHOTT recently delivered several thousands of smaller segmented hexagonal BG3 filters (see figure 8) for a cosmic ray experiment. Each detector set-up consists of 256 (16 x 16) photomultipliers and is covered with a BG3 array. Also for other telescope applications segmentation of the filter area (mosaic filters) may be a feasible, of coarse depending on the filter position within the telescope.

Up to now we discussed the availability of filter glasses in large dimensions, but there is still some more work to do. SCHOTT Guinchard in Yverdon / Switzerland can polish filters up to a maximum diameter of

680 mm, but for the maximum size a minimum glass thickness of 3 mm is required. Coating equipment for interference coatings up to dia. 400 mm is available at SCHOTT in Mainz. Discussion on interference coating requirements and the detailed band-pass specification is required. The cementing of large (and thin) filters is also challenging and will need some process development.

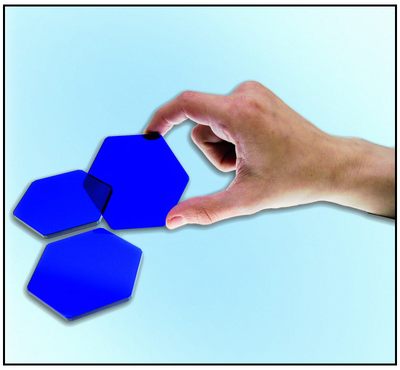


Fig. 6: ZERODUR blank of a large test matrix lens   Fig. 7: Casting of colour glass at the SCHOTT plant in Gruenenplan (left)
Fig. 8: Hexagonal BG3 filters delivered by SCHOTT for a cosmic ray telescope (right)

4. DISCUSSION AND SUMMARY

Large filter glasses and large lenses are needed in future telescopes. These challenging components are a potential critical path. Most of the glass manufacturers may be not able or not interested to develop the technology. Schott has been a partner of astronomy for more than 100 years. With its century of experience in glass production SCHOTT can (almost) do it. The SCHOTT capacities on large optical glasses have been presented in the previous chapters, and also the capacities on large filter glasses. Even at SCHOTT there are some restrictions and there is the need for developments. For some of these challenging elements SCHOTT is probably the only available source. The future demand for special astronomical materials needs coordination. So contact SCHOTT at an early state if you need large filters or huge lenses.

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