

# Challenges in metrology of mirror segments for X-ray telescopes

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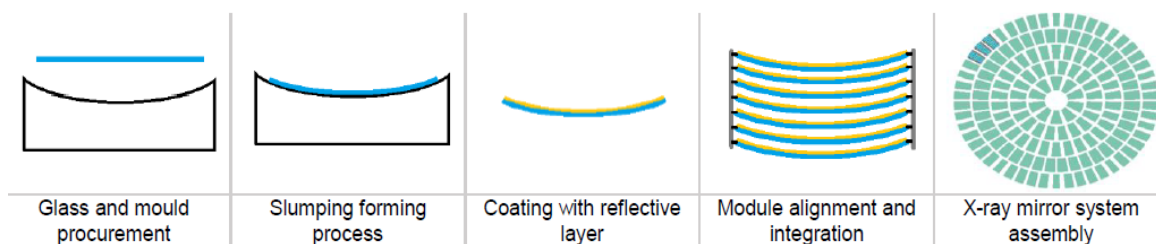
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## Abstract

High angular resolution, large collecting area and reduced weight per unit area are required for astronomical X-ray telescopes of the next generation observatories. New technologies for processing X-ray mirrors are under development to fulfill these needs. One option is to realize a Wolter I type telescope constituted of several hundred nested thin and light-weight X-ray mirror segments. The individual mirror segments need to be coated with an about 100 nm thick film of a high-reflective material to enhance the reflectivity for X-rays. Thereby an accurate shape metrology of the segments is necessary to predict the angular resolution of the astronomical telescope as well as to control the development process of X-ray mirrors. We present the challenges in shape measurements of thin glasses used to control the coating process and first experimental results about the repeatability of the measurements.

## Description of application and background

Current mirror technologies cannot fulfill the challenging requirements of future X-ray telescopes. Consequently new production methods are under development. A promising technology is the hot slumping process [1], developed at the Max-Planck-Institute for extraterrestrial Physics (see fig. 1). This production technology foresees the thermal shaping of originally flat glass foils over a mould to the required Wolter I profile for X-ray mirrors (see fig. 2). This indirect slumping technology offers a potential cost-effective mass production of lightweight X-ray mirrors. The corresponding development of mirror coatings is done at Aschaffenburg University of Applied Sciences [2]. Requirements for the coating are high X-ray reflectivity, low surface roughness, low-stress to avoid shape deformation of the thin substrate, and an application process suitable for serial production.

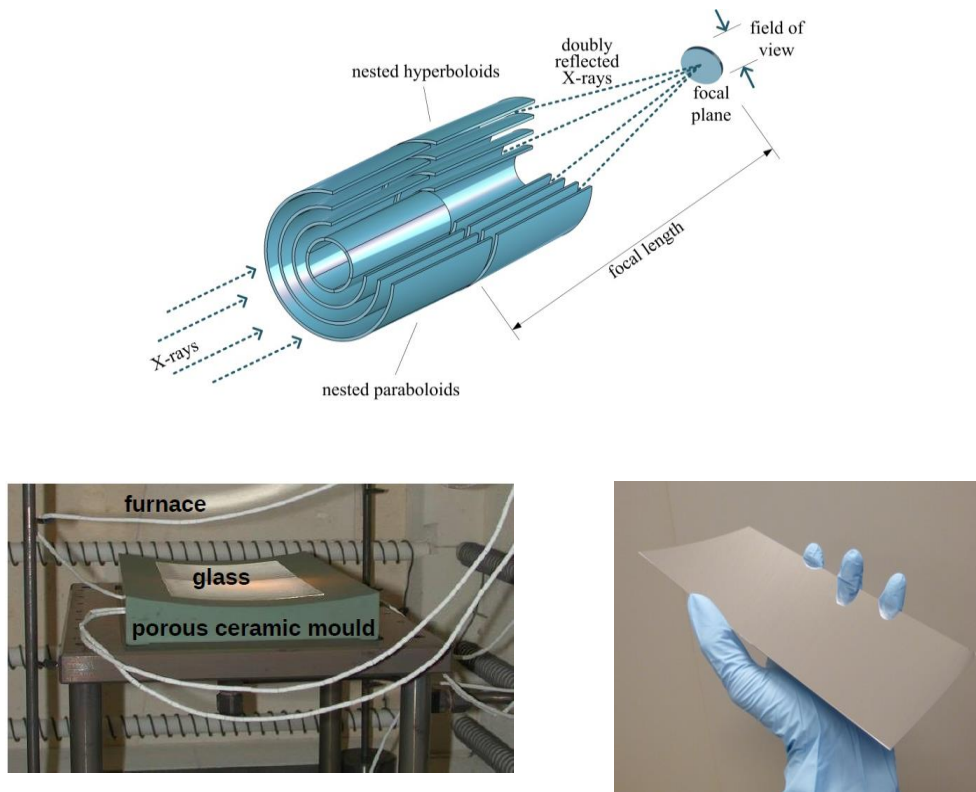


**Fig. 1:** Principle of the indirect slumping technique for X-ray telescope production [1].

## Measurement challenges of X-ray mirror's shape

Submicron accuracy is required for the shape measurements to predict the angular resolution of the astronomical telescope and to control the mirror processing. The surface figure of the glass segments and of the mould used for their production is measured by non-contacting optical topography. Measurements of the shape and roughness of the mould are useful to control the slumping process resulting into a parabola shape on one half part of the glass and to an hyperbola shape on the other part. To derive the stress introduced into the glass substrate by the Iridium coating used here, the shape is measured before and after the coating process for comparison. This implicates stringent requirements on the repeatability of the

measurement (deviations in the height profile  $\ll 1 \mu\text{m}$ ) at different stages of the characterization: high stability of the measurement system itself as well as repeatable influences of external effects on the glass shape. Hence repeatable glass deformation due to gravity effects requires a repeatable sample positioning, whereas temperature, vibrations or noise induced deformations have to be reduced by a good stability of the environmental conditions.

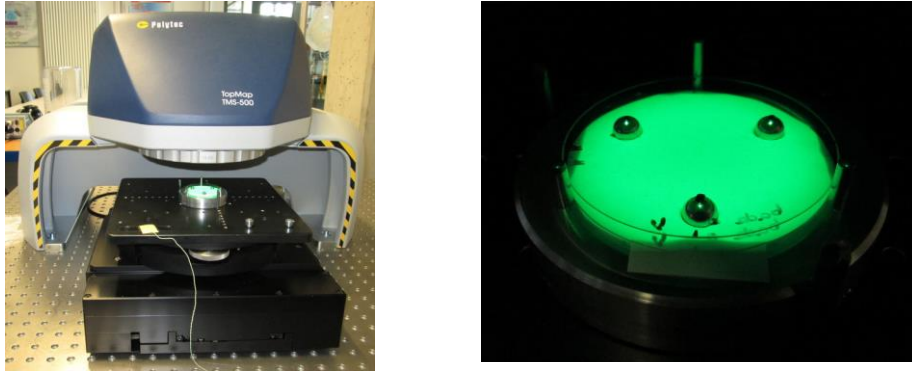


**Fig.2.** Top: Schema of the Wolter I mirror configuration constituted of nested X-ray mirror shells [3]. Bottom: Left: Glass used as X-ray mirror's substrate placed on a porous, concave ceramic mould during the thermal induced slumping process [1]. By this process, the initially flat glass is shaped to parabola on one half part and to hyperbola on the other part according to the shape of the mould. Right: Coated X-ray mirror.

## Experimental set-up

The investigated glass substrates used to control the coating process are 0.4 mm thick wafers ( $\varnothing$ : 50.8 mm) of the type D263Teco from Co. Schott. In the first characterization step, the glass substrates are uncoated, in the second step they are coated with a 100 nm thick reflective Iridium film. A white light interferometer Polytec TMS-500 TopMap [3] is used to perform the shape metrology (see fig. 3, left). Based on Michelson interferometry with a LED light source with a wavelength of 525 nm (coherence length in the  $\mu\text{m}$ -range), this instrument system depicts a vertical resolution below 4 nm. The dimensions of one measurement field correspond to 22 x 16 mm<sup>2</sup>.

To induce a repeatable influence of the gravitation effect on the glass deformation, the samples are supported by a three-point-support (see fig. 3, right). To reduce the influence of vibrations the whole experimental set-up is placed on a vibration isolated table, the measurements are taken in a non-climate controlled laboratory, temperature changes below 1 K are observed during the measurements.



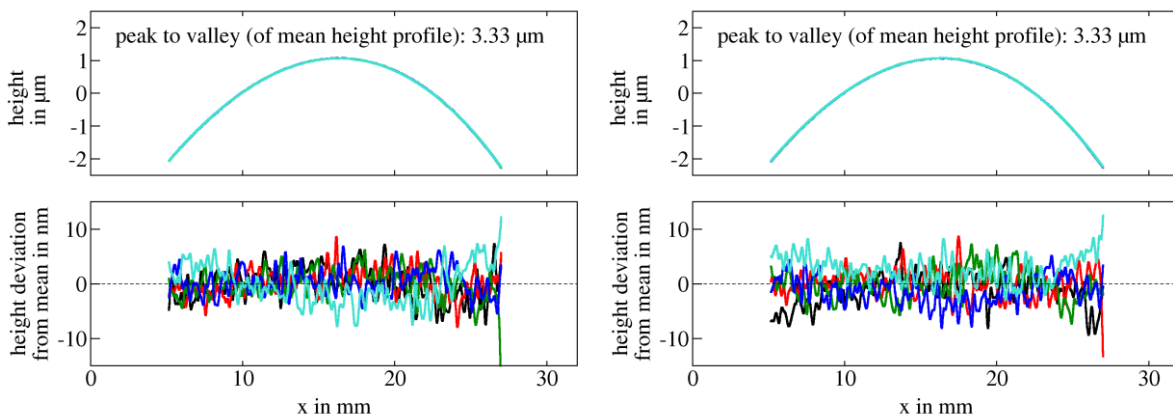
**Fig.3.** Left: White light interferometer Polytec TMS 500 TopMap. Right: Thin glass wafer (D263Teco from Co. Schott,  $\varnothing$ : 50.8 mm, thickness: 0.4 mm) placed on a three-point-support.

## Results and Discussion

In a first step, the shape of a 20 mm thick reference flat sample of Zerodur ( $\varnothing$ : 150 mm) from Co. Bernhard Halle Nachfl. GmbH (deviations from flatness  $< \lambda/20$ , peak-to-valley at  $\lambda = 550$  nm) was measured on an area of  $22 \times 16$  mm<sup>2</sup> by the white light interferometer. The aim of this investigation was to test the ability of detecting low deviations from flatness and the repeatability of the measurement system using an ideal flat and thick sample, for which the influence of gravity effects can be neglected. The measured deviations from flatness lie all below 27 nm, a result which agrees well with the  $\lambda/20$ - specification of the supplier.

Preliminary results about the repeatability of the shape measurements of an uncoated thin circular D263Teco glass wafer are depicted in fig. 4. Two types of measurement series (duration of each serie:  $\leq 10$  min) were performed to characterize the repeatability of the shape measurements without modifying the position of the sample on the one hand and with repositioning the sample on the supporting system on the other hand. In the first serie (left diagrams), five consecutive measurements were taken without repositioning the sample between the measurements. In the second serie (right diagrams), the sample has been repositioned on the three-point-support between each of the five measurements. The height profiles measured along a 22 mm long segment centered on the diameter of the glass wafer are shown in the top diagrams. The peak-to-valley values of the mean height profile lie at  $3.33 \mu\text{m}$  in both cases. The measured shape results from gravitation effect superimposed by internal stress of the glass. On the bottom of fig. 4 the deviation of the measured heights from the mean height obtained for the five measurements is plotted vs. the position  $x$  on the glass diameter. Without repositioning the sample the measurements results are repeatable within  $\pm 12$  nm. Quite similar results of  $\pm 13$  nm were obtained for the deviations when the sample is repositioned on the support between the measurements.

The shape metrology is furthermore checked within a dedicated cross-calibration campaign using instruments of different European research institutions [4]. Besides with the white light interferometer Polytec TMS-500 TopMap, shape measurements were performed with two other instruments a chromatic confocal optical sensor CHRocodile type M4 from Co. Precitec at the Max-Planck-Institute for extraterrestrial Physics [5] and a long trace profilometer type LTP II at the INAF-Osservatorio Astronomico di Brera [6].



**Fig.4.** Height profiles (top) and deviation from the mean height profile (bottom) measured on a 22 mm long segment centered on the diameter of a 0.4 mm thick glass wafer D263Teco ( $\varnothing$ : 50.8 mm) of Co. Schott. Left: without repositioning, right: with repositioning the glass wafer on the three-point-support between each measurement.

## Conclusions and Outlook

The repeatability of the measurements with the white light interferometer on the height profile of the investigated thin glass wafers is quite good on a short measurement time scale (deviations  $< \pm 20$  nm). Further investigations of the repeatability of the measurements on longer time scales are necessary to trustfully analyze the influence of the coating on the glass shape. Furthermore, different supporting systems (including different radial supports) will be tested to study the influence of gravity on the measured glass shapes.

## Acknowledgments

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