International X-ray Observatory (IXO)

Design and development of the IXO mirrors by Innovative Slumping Glass Technologies

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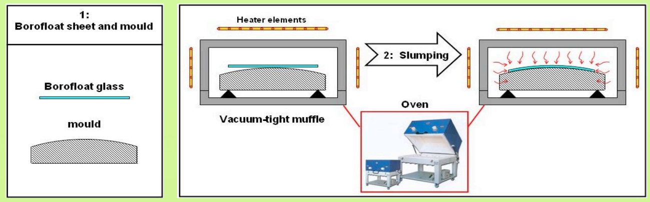
ABSTRACT

At the Brera Astronomical Observatory – INAF (Italy) we are involved in development activities, aiming at the design and development of the IXO mirrors based on slumping glass technique. Our approach is based on the use of thermal slumping of thin glass optics and presents a number of innovative solutions for the implementation of the concept. In particular, our approach foresees the use of a ceramic mould made of SiC for thermal shaping of the glass segments, which occurs exerting a proper pressure during the high temperature shaping process. A thin layer (a few hundred Angstroms) of Pt or Ir is previously deposited on the glass segment, to prevent the adhesion on the SiC mould surface. Therefore this film not only acts as a release agent of the process but, at the same time, it has also the role of reflecting coating of the X-ray mirror (in a sense like it was the role of gold in the Ni electroforming replication method used for the XMM shells). SiC is chosen for its very good T/M characteristics and, in particular for this application, a very high thermal conductivity and very low CTE. SiC mould will be produced via injection moulding process, followed by a the application of a cladding layer (a few tens microns) application of CVD SiC for allowing a superpolishing of the surface until a roughness of a few Angstrom rms is achieved. Once the mirror segments are produced, they are integrated in petals by means of air-bearings supports, that allows us to maintain the proper shape of the segments without deformations. The segments are stacked into the petals by the use of connecting ribs, glued to the front surface of each mirror and to the rear of the next one.



The ***Hot Press Direct Slumping*** concept.

The proposed approach consists in the following steps:

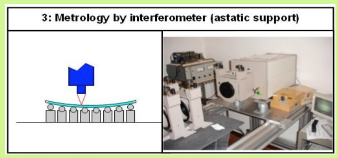


Fig. 1: **Hot Press Direct Slumping concept diagram.**

- a mould having the complementary shape desired for the optical segment is manufactured in a suitable material that has a CTE as similar as possible to that of the glass to be slumped. The microroughness surface finishing of the mould will be similar to that necessary for the slumped segment. This requirement is necessary because the procedure foresees to copy the geometry of the mould and its higher spatial frequencies and in particular a part of its microroughness;
- after a deep cleaning of the two components (mould and glass sheet), they are placed in a muffle. The muffle permit to remove the air convection, with advantages in terms of homogeneous heat distribution, and it protects from the dusty ambient of the oven;
- the muffle is placed inside the oven and a suitable thermal cycle is then applied. During the slumping process a pressure is applied on the glass so to force it against the mould surface. This ensures the full contact of the glass against the mould. At the end, the glass sheet will have copied the shape of the mould;
- the measurement of the optical shape of the segment is done using an astatic support and an interferometer.

PRESENT RESULTS OF HPDS OPTICAL SEGMENTS

This phase concern the individuation and refinement of the best suitable thermal cycle and pressure to be applied. After having developed a suitable procedure and technology, we have started a series of slumping tests to investigate some crucial characteristics of this technique: spatial wavelengths copy capability, from shape to microroughness level, and repeatability in term of optical quality of the glass segments manufactured. At this point of the development we have the capability to obtain full contact on all the surface of the glass against the mould and to control the amount of pressure applied. The dust contamination control needs to be improved to obtain fully dust-free mirrors and a high performance clean-room has been constructed.

1. Shape copy capability (optical quality)

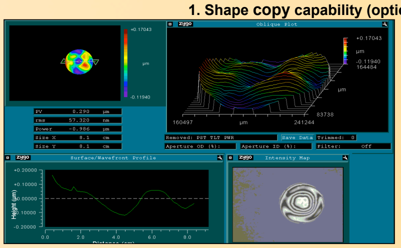


Fig. 2: **Interferometric measurement of an HPDS glass segment (λ/11 on 80 mm) (λ/3 on 130 mm)**

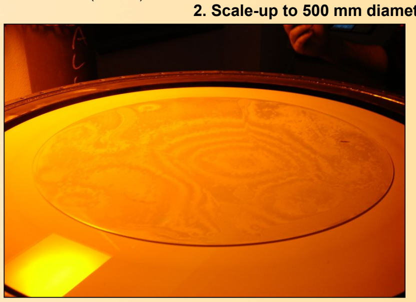
Fig. 3: **Sodium light fringes between mould and glass segment.**

Tests were performed using a convex K20 mould (ϕ = 150 mm) with a radius of curvature of 4000 mm with thin 1.7 mm Borofloat 33 sheet glass.

Repeatability tests performed so far have shown that the limiting factor in obtaining lower shape errors is the mould shape itself.

Fig. 2 and 3 show, as example, an HPDS segment whose shape differs only few tens of nm from the ideal one (~50 nm).

2. Scale-up to 500 mm diameter



This experiment was performed with a max temperature of 650 °C and even if a circular pattern of fringes is visible they weren't up to the edge. The good contact area had a diameter of about 30 cm.

10 fringes = PV 3 μm or 4 arcsec of figure error on 30 cm diam.

The slumping on a sphere require the bending on 2 axis, a more difficult task respect to a cylinder.

To better shape the glass segment it is necessary to increase more the slumping temperature, probably exceeding the sticking temperature (670°C). It is mandatory to have a good release layer.

FUTURE STEP: MOVING TO the IXO X-RAY OPTICS

In the last months we have started the study of a modified slumping technique specifically tailored to lightweight optics for X-ray telescopes with large colleting area like the International X-ray Observatory. To reach the scientific goals of the mission it is mandatory to develop a suitable technology able to manufacture optics with very high performances in terms of effective area (> 3 m^2) and angular resolution (< 5 arcsec), maintaining as low as possible the weight of the optic.
The use of thermally formed glass as substrate for X-ray optics could be an interesting solution. In this framework, the HPDS technique till now developed in our institute must be modified and addressed to this specific topic. The key points that must be deeply investigated are:

- new materials (mould, glass and anti-sticking layer), procedure, thermal cycle;
- different geometry, hence different characterization methods;
- integration and alignment of the shells;

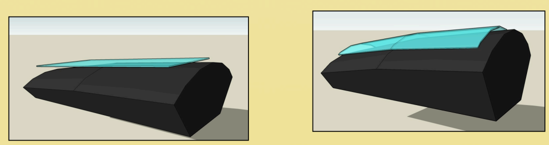


Fig. 4: **Sketch of a possible configuration to slump a glass segment for X-ray optics.**

An important step in developing the technology is the choice of materials for moulds and glass segments. An attractive material for manufacturing the moulds has been individuated in the Silicon Carbide for its thermal, mechanical and optical performances. Using this, or even other, material we have to face with the mould-glass sticking problem. A way to solve this issue is to coat the raw glass segment with an appropriate anti-sticking layer. If well chosen, it can acts also as an X-ray reflecting coating. Last, but not least, the thermal cycle could help in relaxing the stresses introduced during the coating step. We have already successfully tested thin Pt coating (both evaporated and sputtered) on SiC moulds and thin Ir and W coating (sputtered) on Zerodur K20 moulds.

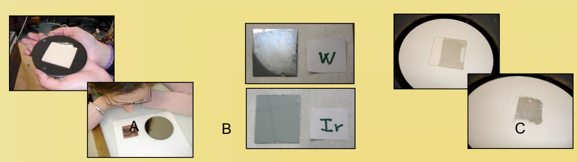
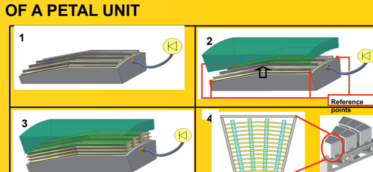


Fig. 5: **Tests of different anti-sticking layers: A) Pt layer on polished SiC mould; B) Ir and W layers on polished K20 mould; C) Pt layer on polished K20 mould.**

INTEGRATION OF A PETAL UNIT



Once the mirror segments are produced, they are integrated in petals by means of air-bearings supports, that allows us to maintain the proper shape of the segments without deformations. The segments are stacked into the petals by the use of connecting ribs, glued to the front surface of each mirror and to the rear of the next one

CONCLUSION

The conclusions that can be drawn after this part of study on the slumping technique indicate that the procedure developed has the potential to reach a very high shape accuracy on the slumped segments, as requested for IXO. It has been determined that the use of pressure to force the glass in full contact with the mould is necessary at the temperature used in these slumping tests. With this approach part of the mould microroughness pass to the slumped glass, hence it should be of 3-5 Å rms or less because the glass will copy either the mould microroughness and its shape at lower spatial frequencies. The results till here obtained with the HPDS technique are mostly limited from the quality of the mould optical surface and not from the slumped segments. We will proceed with a deep investigation of the HPDS here presented because it seems to be a promising technology for the manufacturing of high performance X-ray optics. As shown, a thin Pt layer has been already individuated as candidate both as anti-sticking and X-ray reflecting layer.