NOVEL APPROACHES IN TECHNOLOGIES FOR LARGE LIGHT-WEIGHT X–RAY SPACE TELESCOPES

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ABSTRACT

The future large X–ray astrophysics space missions (such as the ESA XEUS) require very light-weight but large and precise X-ray mirror shells. This trend is general since the scientific need is to achieve better sensitivity at very high angular resolution. Clearly, the developments of completely innovative techniques and approaches are necessary. We describe and discuss the possible alternative techniques. They include Si wafers shaping, thin glass technology and glass thermal forming, as well as glossy metals and glossy carbon.

Key words: X–ray telescopes, X–ray optics.

1. INTRODUCTION

Imaging X–ray mirrors represent a key component of X–ray astrophysics missions. Various technologies for their production exist, the most important ones being the galvanoplastic replication and the direct polishing of the mirror shells. The future X-ray astrophysics missions such as the ESA's XEUS (Aschenbach et al. 2001) will however require innovative technologies and approaches resulting in lighter mirror shells in order to achieve high sensitivity and high angular resolutions at a still reasonable weight of the mirror assembly (Hudec et al. 2004, 2005).

2. GLASS AND GLASS THERMAL FORMING

Glass has 4 times less volume density if compared with nickel in common use. Highly flat and highly smooth thin glass foils may serve in various future experiments. Glass foils for the X–ray optics can be used either as flat or curved, while the curved foils can be either bent (without heat) or thermally shaped. Bent glass foil optics has been already successfully used for a test laboratory sample for a XEUS-like optics module (the 0.75 mm thick and 300 x 300 mm large glass foils were beent to achieve the required parabolic profile). Here we report on the project supported by the Ministry of Industry and Trade of the Czech Republic and focusing on thermal glass forming. We also report on the first preliminary results obtained within this project. The thermal forming of glass is not a new technology since it has been used in various regions of glass industry and glass art as well as in production of Cerenkov mirrors. However, the application of this technology in X-ray optics is related with the need to significantly improve the accuracy and minimize the errors. As a first step, small (10 x 5 cm, 0.75 mm thick) glass samples of various types provided by various manufacturers have been used and thermally shaped. The geometry was either flat or curved (cylindrical). The project continues with larger samples (recently 300 x 300 mm) and further profiles (spherical and parabola). Although we focus on curved shells since the main goal is to develop a technology meeting the requirements of the large future X-ray telescopes with Wolter geometry, the replication of flat foils represent another important application since this approach is expected to improve the flatness of X-ray flats (foils) needed e.g. for Lobster Schmidt lenses.

The small glass samples were thermally formed at the Center for Advanced X-ray Technologies, Reflex, Prague, as well as at the Institute of Chemical Technology in Prague. For large samples (more than 300 mm), we expect to use the thermal glass forming device available at the Compas Co. in Turnov as well as their expertise in thermal shaping of large (diameter 0.5 to 1 m) glass Cerenkov mirrors (spherical surfaces). Already for these tests, our idea is to develop technology suitable for mass and inexpensive production of thin X-ray optics shells. This means that we avoid expensive mandrels and techniques not suitable for mass production or too expensive.

Numerous glass samples have been shaped and tested. The shapes and profiles of both mandrels as well as the resulting glass replicas have been carefully measured by metrology devices. The preliminary results show that the quality of the technology process and resulting quality of the thermal glass replica can be significantly improved by the optimisation of the material and design of the mandrel, by the modification of the thermal forming process, as well as by the optimisation of the temperature. After the (partly significant) modifications and improvements we have obtained the resulting deviation of the thermally formed glass foil from the ideal designed profile less than 1 micron (peak to valley value). This value is however strongly dependent on the exact temperature as well as on other parameters, so we believe that a significant further improvements are possible. The fine original microroughnes (typically better than 1 nm) of the original float glass foil has found not to be degraded by the thermal forming process.

3. SI WAFERS

Another alternative recently considered as one of most promising, is the use of X–ray optics based on commercially available silicon wafers manufactured for purposes of semiconductor industry. Silicon is relatively light (volume density 2.3) and already during the manufacture process is lapped and polished (either on one or on both sides) to very fine smoothness (better than 0.1 nm) and thickness homogenity (of order of 1 micron). We have created a collaboration in the Czech Republic to study and to exploit the high precision X–ray optics based on Si wafers. For the tests, Si wafers developed and produced by the ON Semiconductor Company in the Czech Republic as well as by other Czech manufacturers have been used. Various techniques and approaches how to shape the Si wafers to fine and accurate optical surfaces have been exploited. This is not trivial since Si wafers are difficult to shape. The results are promising and justify the continuation of these efforts. Our recent goal is to achieve very high accuracies in shape while maintaining the fine surface microroughness and to minimise the internal stress which is necessary for the high precision and for the very long lifetime of the space telescope.

4. AMORPHOUS-GLASSY METALS AND GLASSY CARBON

The metallic amorphous alloys have very interesting physical properties. Mechanical properties of amorphous alloys are comparable with those of high strength steel. As an example, the mechanical properties of amorphous Ni/Fe alloy are nearly four times better than those of crystalline Ni.

The another promising alternative is the glassy carbon. The glass-like carbons have bulk densities around 1.5 g cm^{-3} (although they can be as small as 1.4 g cm^{-3} and even 0.6 g cm^{-3} if an extended porosity may be accepted) which are almost equal to those of the conventional synthetic graphite and lower than any previous material considered for future large area X-ray mirrors. The glossy carbons with high porosity can even reach bulk densities of 0.6 g cm^{-3}. The beending strength of glass like carbons amounts to 50-200 MPa, the Young's modulus to 20-32 GPa, and the C.T.E. amounts to about 1 x 10^{-6} C^{-1}. Glass like carbons are hard materials as shown by their shore hardness of 100, and of 70-80 after graphitization. However, they have little mechanical shock resistance and belongs to typical fragile materials. This can be, on the other hand, affected by the selection of a suitable filler. They exhibit low self-lubricity and high abrasion resistance reflecting their special structures, compared with conventional graphite. The applications of glass-like carbons have been rather limited for the past few dozens of years. It is just recently that they have attracted much more interest in terms of industrial applications. Among the parameters, the glass like carbons seems to be favourable because of their low density and low thermal expansion. The large-size composite glass-like carbon thin plates have been already successfully produced for fuel cell separators (Marsch et al. 1997).

5. CONCLUSION

There are several promising alternative methods to produce large precise and lightweight X-ray mirror shells for future X-ray astronomy satellite missions. The first prototypes and tests have indicated that the thermally formed glass foils and shaped Si wafers are among the suitable techniques to be further exploited.

6. ACKNOWLEDGMENTS

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