The fabrication of replicated optics for hard x-ray astronomy

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Abstract: We describe the fabrication process for producing shallow-graze-angle mirrors for hard x-ray astronomy. This presentation includes the generation of the necessary super-polished mandrels, their metrology, and the subsequent mirror shell electroforming and testing.

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1. Introduction

We are developing shallow-graze-angle high-resolution replicated mirrors for the hard x-ray region. Our fabrication process involves electroforming a nickel replication off the surface of a super-polished electroless nickel (EN) coated aluminum mandrel. This approach was first pioneered in Italy [1], and has previously been utilized for the low energy x-ray mirrors on the XMM mission [2] among others. However, hard x-ray optics require a differing production path from that of the low energy shells that have been developed in Europe.

To demonstrate the viability of our approach we initiated the first phase of the High-Energy Replicated Optic (HERO) program. This engineering/demonstration flight scheduled for May 2000 will provide a balloon payload consisting of 2 identical 3.0-meter focal length mirror modules; each containing a nested array of 3 mirror shells of diameters ranging from 40mm to 48mm (**Table 1**). We have fabricated three mandrels: HXM340, HXM344, and HXM348 and from these we have replicated the necessary optics.

Phase 2 of the HERO program will entail the production of sixteen 6-m-focal-length mirror modules, each containing a nested array of 14 mirror shells of diameters ranging from 50mm to 94mm [3]. This flight is slated for the fall of 2002.

Table 1. HERO Phase 1 mandrel and mirror configuration

Mandrel material	6061 Aluminum with 0.15mm EN coating
Number of mirror modules	2
Mirror shells per module	3
Inner shell diameter	40mm
Outer shell diameter	48mm
Total shell length	610mm
Focal length	3m
Type	Conic approximation to Wolter I
Shell fabrication process	Electroformed nickel replication
Shell thickness	0.25mm
Inside shell coating	Sputtered iridium
Angular resolution	~30 arc sec to 50 keV (half-power-diameter)

2. Mandrel Fabrication

2.1 CNC Turning & Electroless Nickel Coating

We begin the mandrel fabrication by CNC-lathe-turning a cylindrical 6061-aluminum bar to print specifications and prescribed figure. Before plating with electroless nickel, the mandrels are cleaned to remove surface contaminants that may affect the adhesion of EN to aluminum. Approximately 0.15mm of EN is deposited onto each mandrel and then the mandrels are baked out to improve the adhesion between the EN coating and aluminum.

2.2 Precision Grind

Precision grinding is performed on a CNC Kellenberger Kel-Varia cylindrical grinding machine [4]. The grinding process removes between 0.05mm and 0.07mm of EN from the mandrel surface. The surface finish is achieved by first rough grinding with an 80 grit stone to 0.0127/0.025mm of the prescribed figure. Then a two point steady rest is positioned about 25mm from the center of the mandrel to reduce deflection and chatter. During the final grinding cycles, a 600 grit stone improves the surface finish to about 600 Å.

2.3 Polishing, Super-Polishing, and Metrology

A modified Enco lathe serves as our polishing machine (**Fig. 1**). Pitch was formed into radius cut aluminum laps of lengths ranging from 305mm to 25mm. The smaller laps allow figure errors to be corrected by "zone" polishing. We experimented with various pitch grooving patterns, but finally settled upon a very compliant triangular pattern [5]. Stepping down of Al_3O_2 polishing compounds removed the machining features of precision grinding. Periodically, the mandrels were scanned with a long trace profilometer (LTP) to determine the axial figure error along each segment (**Fig. 2**). Once the surface roughness of each segment reached about 10 Å rms and the axial figure error was <1.0 micron, we super-polished with silica colloidal compounds to achieve 3 to 4 Å rms finishes. Before replication, mirror performance predictions are done using mandrel metrology data from WYKO surface roughness, LTP profile, circularity, and cone angle measurements.

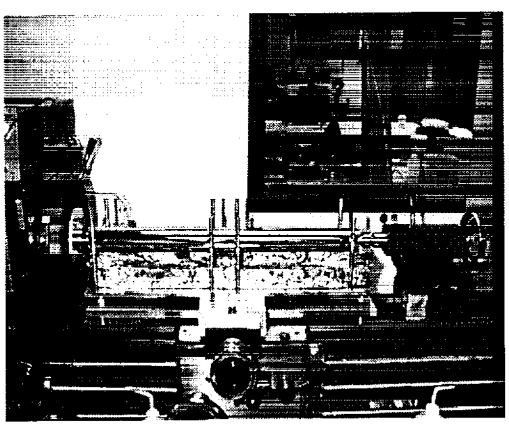

Fig. 1. Modified Enco lathe for polishing.

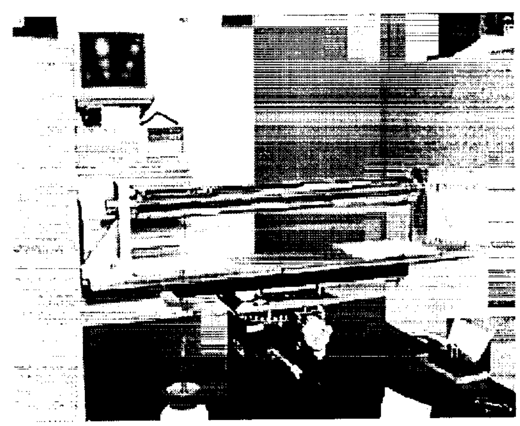

Fig. 2. HERO mandrel on LTP.

3. Mirror Fabrication

3.1 Mirror Replication

Once the performance prediction from the mandrel metrology is acceptable, the mandrel is extensively cleaned to remove residual surface contaminants, i.e. fingerprints, polishing compounds, and machine oils. Then the mandrel surface is passivated to reduce adhesion (this permits shell separation from the mandrel without damage), and a shell is electroformed. A special low-stress process developed at MSFC achieves the electroforming. The resulting nickel alloy deposit is an ultra-low-ductility high-strength "glassy" metal, which mechanically behaves like a ceramic. After electroforming, the mandrel plus attached shell is maintained at 45°C, plating bath temperature, and transported for separation. Separation is achieved by immersing the mandrel and unreleased shell into liquid nitrogen. The large difference in thermal expansion coefficients between the aluminum mandrel and electroformed shell allows a smooth separation of the shell from the mandrel. After the mandrel reaches room temperature, we visually inspect it for damage and then perform roughness measurements to determine any surface degradation.

3.2 Mirror Testing and Results

Five of six Phase 1 flight shells have been replicated and tested. Testing of uncoated nickel shells have demonstrated performances equivalent to those predicted from mandrel metrology (~30 arc-seconds HPD). This indicates that the replication process produces a near exact copy of the mandrel surface roughness and axial figure. Replicated mirrors await iridium coating and nesting into mirror modules for the May 2000 balloon flight (**Fig. 3**).

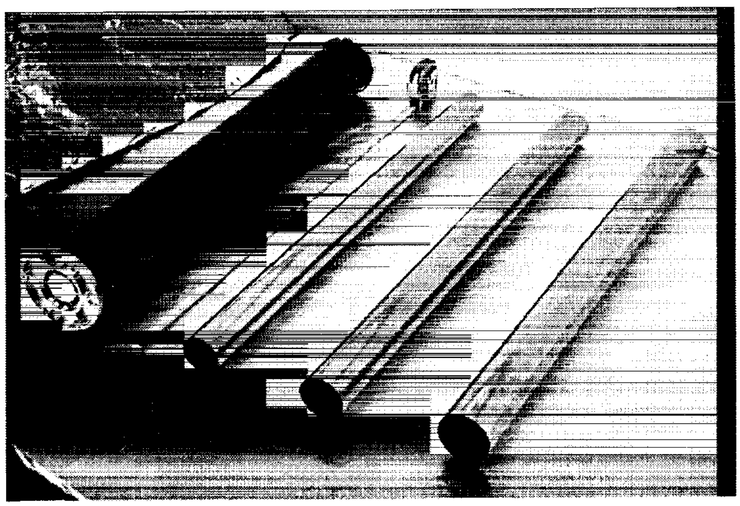

Fig. 3. HERO mirror module and 3 mirror shells.

4. References

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