LA-UR - 81-1611

CONF-810651--1

TITLE: EPOXY REPLICATION FOR WOLTER X-RAY-MICROSCOPE FABRICATION

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MASTER

SUBMITTED TO: 1981 Topical Conference on Low-Energy X-Ray Diagnostics
Lawrence Livermore National Laboratory
June 8-10, 1981

University of California

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UNITED STATES
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Epoxy Replication for Wolter X-Ray Microscope Fabrication

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ABSTRACT

An epoxy replica of a test piece designed to simulate a Wolter x-ray microscope geometry showed no loss of x-ray reflectivity or resolution, compared to the original. The test piece was a diamond-turned cone with 1.5° half angle. A flat was fly-cut on one side, then super- and conventionally polished. The replica was separated at the 1.5°-draft angle, simulating a shallow angle Wolter microscope geometry. A test with 8.34 Å x rays at 0.9° grazing angle showed a reflectivity of 67% for the replica flat surface, and 70% for the original. No spread of the reflected beam was observed with a 20-arc second wide test beam. This test verifies the epoxy replication technique for production of Wolter x-ray microscopes.

INTRODUCTION

Wolter x-ray microscopes are often the imaging diagnostic of choice for laser fusion applications. They can provide micron-scale resolution, and collection solid angles of order 10^{-3} sterradian,(1-2) unlike pinhole cameras and Kirkpatrick-Baez x-ray microscopes.(3) A true image is formed by a Wolter microscope. This image can be time resolved by a streak camera(4); time resolution is more difficult for images that must be reconstructed, such as from uniformly redundant arrays(5) or zone plate apertures(6). Wolter microscopes have proved difficult to fabricate, with typical production costs of >$10^5. The near-target environment in a laser-fusion target chamber is not ideal for expensive optics. Target debris and radiation can damage the high-quality x-ray reflective surfaces. A large advantage would therefore accrue from the production of several x-ray optical elements from a single master.

EXPERIMENT

We report a test of epoxy replication that demonstrates essentially perfect replication in a grazing angle conical geometry. This technique may be applied to the "mass" production of Wolter microscopes.

Our test piece for replication is shown in Fig. 1. The "flat cone" mandrel was produced by diamond turning and conventional polishing. It is a frustum of a cone, 25 mm high and 20 mm in diameter at the narrow end. The cone half angle is 1.5°. A flat section 3 mm wide was fly cut parallel to the side of the cone. The substrate was aluminum, plated with electroless nickel for diamond turning. The flat was pol[illegible]ed and superpolished to provide a low-scatter [illegible]sh. The central halfwidth of the flat was specified flat to ± 5 arc seconds. This design was chosen to provide a fla[illegible] surface that can be easily tested for x-ray reflectivity and scatter, superposed on quasi- axi-symmetric geometry. Problems associated with separating a replica at a grazing angle should be apparent in the replica of the flat sector.

A replica of the test mandrel was produced using a standard epoxy technique, by Mr. Bernhard Bach of Hyperfine, Inc.(7) The nickel mandrel was evaporatively coated with approximately 2000 Å of nickel. A conventionally machined replica substrate was coated with epoxy, and mated to the mandrel. The epoxy layer was approximately 50 µm thick, but, since the replica substrate had no flat, the epoxy thickened to 125 µm at the flat section. The epoxy was cured at 50°C. When the assembly was cooled to room temperature, the mandrel and replica were separated mechanically. No problems were encountered in separation.

The mandrel and replica flats were tested with a collimated fan beam of 8.3 Å x-rays. The test apparatus is shown in Fig. 2. Two adjustable slits collimate the x-ray emission from a Manke-type x-ray tube. The slit spacing of 14 µm is chosen to minimize the angular spread of the emergent beam; this width is a compromise between geometric and diffraction spreading. The sample to be tested is mounted on a stage, which can be rotated, and moved in and out of the beam. The detector is film or a proportional counter, and is mounted on a XYZ mount to scan the reflected beam.

RESULTS

The proportional counter was used for a quantitative measurement of x-ray reflectivity. Counter acceptance was defined by a 0.51-mm pinhole, which corresponds to an angular resolution of 3.5 arc-min.

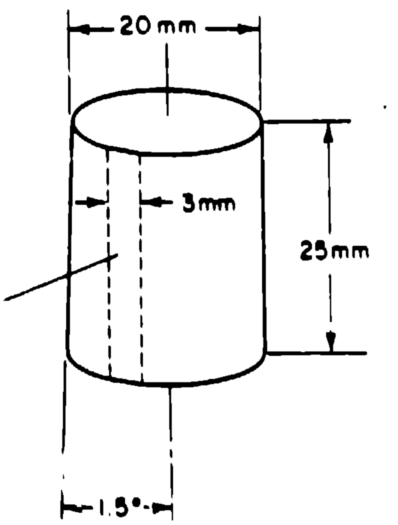

Fig. 1. Sketch of the "flat cone" test mandrel. The test surface is a flat on the side of 1.5° half-angle cone.

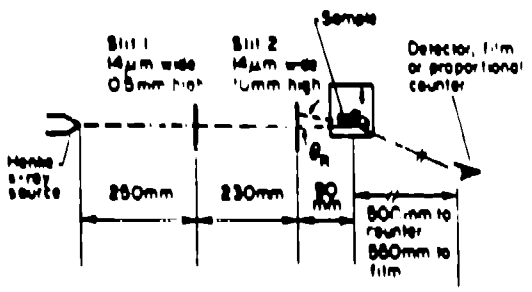

Fig. 2. Plan view of the x-ray test assembly (not to scale).

X-ray scattering from imperfect surfaces typically occurs at angles of ±1-10 arc-min.(8-10) Much of the scattered flux will thus fall outside the acceptance of the pinhole, so that the existence of wings in a horizontal scan of the reflected image indicates surface roughness. Figure 3 shows horizontal scans across the direct beam, and the reflected beams from the flat section on the mandrel and replica. The grazing angle was 0.92°. The scans from the two reflected beams are very similar. Little energy is scattered into the wings by the mandrel, and the replica reproduces this good performance. The specular reflectivity was determined from the ratio of the peak intensities. Measurements at a series of vertical positions were taken to average over vertical variations in the intensity of the Henke tube, projected through the slits. Errors in the peak reflectivities are determined from the scatter of the ratio of the direct and reflected beams at the different vertical positions. The peak reflectivity of the mandrel at 8.34 Å and 0.92° was 0.700 ± 0.022 (1σ); the reflectivity of the replica was 0.668 ± 0.014. The calculated reflectivity of nickel at the same wavelength and angle is 0.76. Both surfaces are thus very good, and there is no significant degradation of the reflectivity of the replica.

The width of the specular peak in the proportional counter scans is determined by the pinhole diameter. No widening of this peak is observed, as might be caused by distortion of the surface figure in manufacture or replication. To look with greater sensitivity for such an effect, high resolution images of the direct- and replica-reflected beam were taken on 2497 film. In this case, the angular resolution of the test was set by the divergence of the test beam. Fig. 4 shows density scans of the direct and replica reflected image. There is no broadening of the FWHM of the reflected beam, which indicates arc-second fidelity of the surface flatness in replication.

Measurement of a flat surface replicated in a 1.5° grazing incidence geometry shows a low-scatter, flat replica surface. The epoxy replication technique thus offers an inexpensive technique of reproducing Wolter geometry x-ray microscopes. This result corroborates tests of replication, at a much larger scale, for Wolter x-ray telescope fabrication.(11)

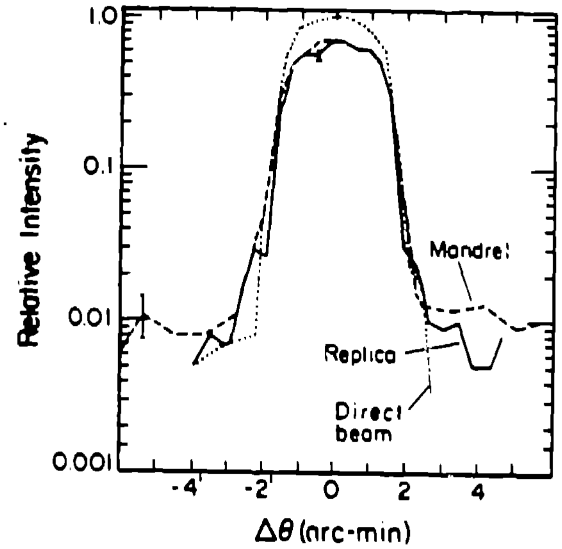

Fig. 3. Horizontal proportional counter scans of the direct and reflected beams. The x-ray wavelength was 8.34 Å; grazing angle was 0.92°.

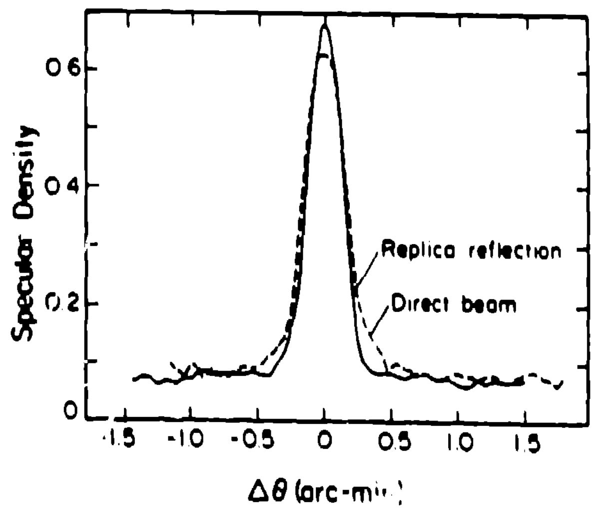

Fig. 4. Densitometer trace of the direct- and replica-reflected beams.

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