Blazed gratings for X-ray astronomy fabricated by grayscale e-beam and nanoimprint

Jake McCoy[1*], Randall McEntaffer[1], Chad Eichfeld[2] and Marc Verschuuren[3]

*[1]The Department of Astronomy & Astrophysics, Pennsylvania State University. 525 Davey Laboratory, University Park, PA, USA. *jam1117@psu.edu*
[2]Materials Research Institute, Pennsylvania State University, N-153 Millennium Science Complex, University Park, PA, USA.
[3]Philips SCIL Nanoimprint Solutions. De Lismortel 31, 5612 AR, The Netherlands.

The majority of spectral lines relevant in high energy astrophysics exist at soft X-ray wavelengths (6-62 Å), where diffraction gratings dominate over energy-dispersive detectors such as microcalorimeters. In a typical X-ray grating spectrometer, arrays of gratings are positioned to intercept and disperse the radiation coming to a focus in a Wolter-I telescope where a detector, such as a CCD camera, placed at the focal plane is used to image the dispersed spectrum. Reflection gratings suited for this application require a custom groove layout with variable line spacing over a large area (tens of square centimeters) to match the convergence of the telescope and blazed groove facets to maximize throughput in a particular band of interest [1]. For a given geometrical collecting area for spectroscopy, sensitivity is proportional to the diffraction efficiency of the gratings. Further, spectral resolving power hinges groove spacing precision over a large area. Therefore, the study of grating fabrication is of particular importance for improving the spectroscopic capabilities of future instruments. The reflection grating spectrometer on board XMM-Newton, which utilizes replicas of a mechanically ruled master grating, has been in use for 15 years and had provided large amounts of scientific return. Leveraging from this instrumentation, next-generation X-ray reflection gratings are under development to improve spectral resolving power and sensitivity for future observatories [2].

Beyond mechanically ruled gratings, the fabrication process for blazed X-ray gratings has largely centered on the production of a large-area master grating through techniques in electron-beam lithography, plasma etching and anisotropic wet etching using potassium hydroxide (KOH) in monocrystalline silicon to provide a blaze. Then, this master grating can be used to direct-stamp many replicas using ultraviolet assisted nanoimprint lithography (UV-NIL) [2,3,4,5]. However, there are some limitations that prevent these gratings from meeting the performance requirements. As a result, alternative lithographic techniques have been explored to manufacture these blazed gratings. In particular, grayscale e-beam lithography (GEBL) coupled with polymer reflow is being pursued to fabricate blazed grating topographies in positive tone electron-beam lithography resist such as PMMA and ZEP520; this technique is known in the literature as thermally activated selective topography equilibration (TASTE) [6]. Additionally, as an alternative to UV-NIL, grating replication efforts are moving toward substrate conformal imprint lithography (SCIL) [6], which is beneficial especially for large areas. In contrast to direct-stamp UV-NIL, the SCIL process uses a flexible stamp formed from the master template for imprinting. Further, SCIL is compatible with silica-based NanoGlass sol-gel imprint resist that has been found to exhibit low facet roughness when coated with metals for soft X-ray reflectivity.

TASTE is currently being pursued at the Pennsylvania State University Materials Institute Nanofabrication Laboratory to fabricate X-ray grating masters [7]. Additionally, SCIL is being pursued in collaboration with Philips SCIL Nanoimprint Solutions to produce replicas for X-ray spectrographs on board sounding rocket experiments. Here, results of the integration of TASTE and SCIL for grating fabrication along with X-ray optical tests results characterizing diffraction efficiency are presented (see Figs. 2, 3 and 4).

References

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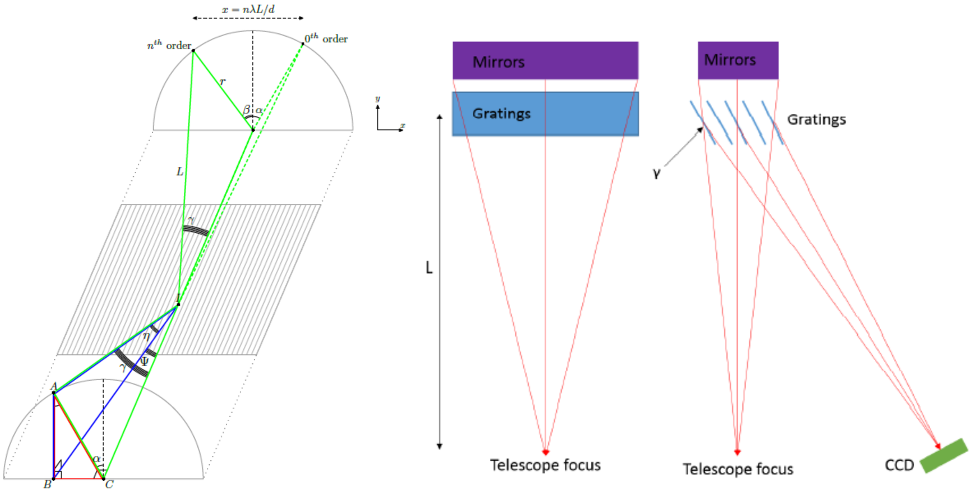

Figure 1: Off-plane, grazing incidence grating geometry (left). Gratings integrated in a Wolter-I telescope (right).

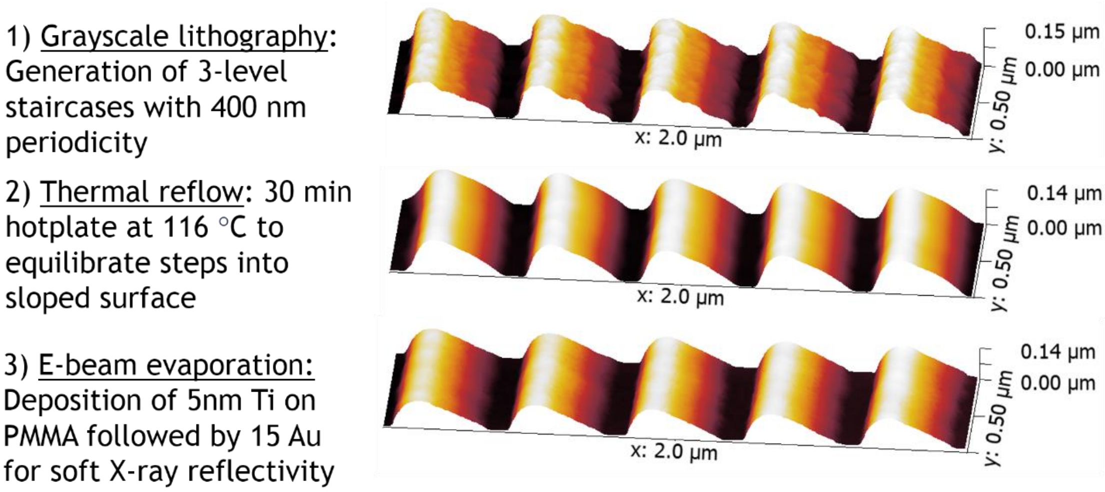

Figure 2: AFM measurements of TASTE grating patterns in PMMA [7].

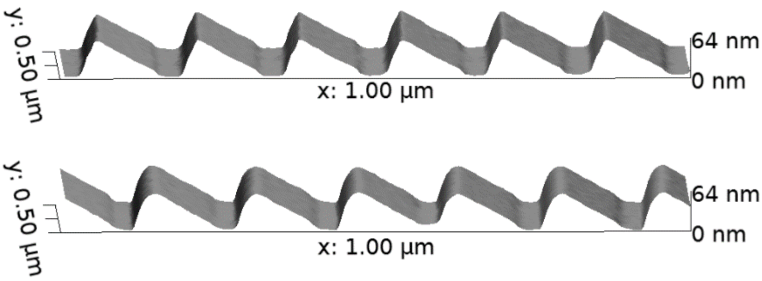

Figure 3: AFM measurements of gratings fabricated using SCIL in sol-gel resist, bare (top) and Cr/Au coated (bottom). Replicas produced from a KOH-etched master grating.

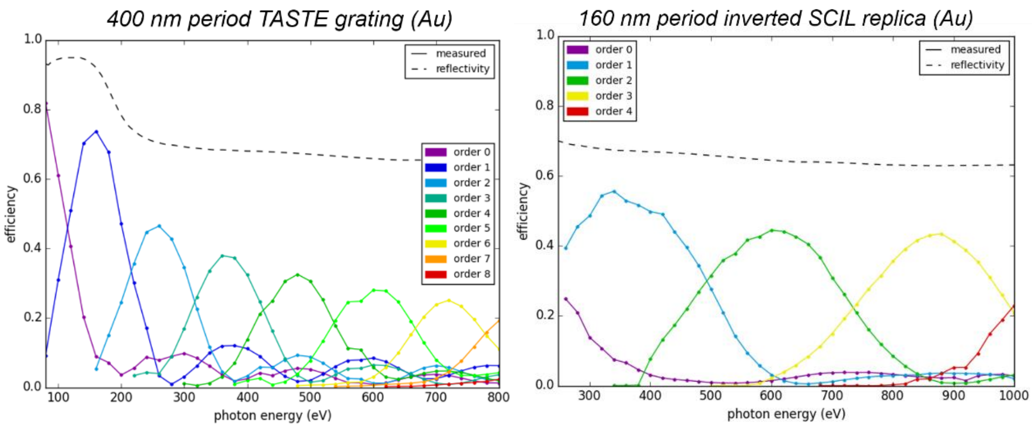

Figure 4: X-ray optical test results gathered from the Advanced Light Source at Lawrence Berkeley National Laboratory: The TASTE grating from Fig. 2 (left) and the SCIL imprint from Fig. 3 (right).