Qualification and performance of the Low-Energy X-ray Reflectometer (LEXR)


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INTRODUCTION

With a number of upcoming spaceborne and ground-based observatories equipped with X-ray telescopes that rely on high throughput at low energies, it is crucial to characterize these optics at the relevant energies to obtain a detailed understanding of their behavior and performance. DTU Space has commissioned a state-of-the-art Low-Energy X-ray Reflectometer (LEXR) with the purpose of studying thin-film performance of especially low-Z X-ray coatings.

Figure 1: Artist’s rendition ATHENA. Credit: ESA

Aiding in the development of ATHENA coatings

One of the primary uses of LEXR is the fast characterization of mirrors to aid in development of coatings for ESA’s Advanced Telescope for High-ENergy Astrophysics (ATHENA). ATHENA’s current baseline coating design is an optimized Ir/SiC bilayer (10 nm/4 nm). While the Ir coating reflects well across the 0.3-12 keV range of ATHENA, the low-Z top layer is added to improve the low-energy reflectivity, in particular to meet the telescope effective area requirement at 1 keV. Mirror manufacturing and processing steps as well as natural contaminants such as hydrocarbons may modify the performance of these mirrors, particularly for lower energy X-rays that are more sensitive to the presence of low-density materials.

With the addition of LEXR operating at 1.487 keV to our existing 8.048 keV reflectometer, DTU Space has characterization capability at two reference energies at either end of the spectrum of interest for ATHENA.

LEXR utilization

LEXR was installed and brought into operation in the fall of 2019 and has since been used extensively for investigation of the effect of ATHENA mirror processing steps such as annealing and chemistry but also to qualify test coatings for e.g. BeATrix and the upcoming BabyAXO axion observatory. The 1.487 keV photons reveal the presence of surface contaminants as demonstrated on Figure 5.

Figure 2: Sketch of LEXR (right) and its beam path (top). Measurements in mm. A: Microfocus source. B: Plane-parabolic collimating KB mirrors. C, G: Slits D: Monochromator. E: Beam shaping slit. F: Sample stage. H: 2D CCD detector

SYSTEM PERFORMANCE

The vacuum chamber wall limits the 26 range to 35 deg. For standard specular measurements the dynamic range is 6 orders of magnitude but long exposures may be used for nonspecular measurements giving 8 orders of dynamic range.

Figure 3: Demonstration of the angular and dynamic range of LEXR.

LEXR is equipped with an Al source and appurtenant monochromator. These may be changed if another energy is desired. This source-monochromator setup produces a beam collimated to 7 arcmin with a 99.3% purity of Al K\alpha photons.

Figure 4: Reflectance of monochromator around its Bragg peak. The discrepancy of 6.2-6.3 deg is the reflectance of Al K\alpha photons.

Figure 5: Demonstration of hydrocarbons altering reflectance of a mirror. This effect is not discernable at e.g. 8.048 keV.

FREQUENCY RANGE OF CHARACTERISTIC LENGTHS

The mechanical limit of 17.5 deg inθ corresponds to 4.53 nm\(^{-1}\) in reciprocal space. With a standard 2 mm opening of the detector slit, roughness with a characteristic length \(\xi \sin(\theta) \geq 410\) nm scatters into the detector opening. Varying detector acceptance widths can be used to probe different bandwidths of roughness correlation lengths as illustrated on Figure 6 where \(\psi = 2\pi/\xi\). An alternative method is to scan offset in \(q_x\), as the measurements shown in Figure 7.

Figure 6: Illustration of the LEXR scattering geometry in Fourier space.

Figure 7: Examples of offset specular measurements on two types of mirrors showing a difference in characteristic lengths between samples

CONCLUSIONS

With excellent characterization capability at 1.487 keV, LEXR is an useful tool for qualification of thin films and in particular low-density overlayers. High resolution measurements of different types give a detailed understanding of coating behavior and surface morphology.