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Dual Function EUV Multilayer Mirrors for the IMAGE mission

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Abstract

We have developed a new family of EUV multilayer mirror coatings using uranium. Using this approach we have coated a set of six mirrors for the EUV Imager, a component of the IMAGE mission. This mission is a Medium Explorer (MIDEX) program, which is scheduled for launch early in 2000. The EUV Imager will study the distribution of He^+ in the Earth's plasmasphere by detecting its resonantly scattered emission at 30.4 nm (41 eV) and will produce images of the structure and dynamics of the cold plasma on a global scale. There is, however, a bright emission at 58.4 nm (21 eV), which comes from neutral helium in the earth's ionosphere which also must be blocked. These photons are at too high an energy to filter with aluminum but at too low an energy to have negligible reflectance from most materials commonly used in EUV mirrors. Thus, a multilayer system which satisfied two optical functions, high reflectance (>20 %) at 41 eV and low reflectance (<2%) at 21 eV, were designed and successfully fabricated.

Such mirrors with dual optical functions in the soft x-ray/EUV had not previously been designed or built. These specifications were particularly challenging because many materials have higher single layer reflectances at 58.4 nm than at 30.4 nm. Essentially, the mirror must have low reflectance at 21 eV without loss of reflection at 30.4 nm. This was accomplished. The top part of the multilayer, which reflects well at 30.4 nm, also acts as antireflection layers at 58.4 nm. In the past, multilayers usually have consisted of periodic bilayers. We have explored the use of aperiodic mirrors in place of the standard periodic designs. Along the way we have created the computational tools, which include genetic algorithms, to optimize selection of materials and thicknesses. We are currently in the process of building up an EUV characterization system and developing a general way of measuring the optical constants of air-sensitive thin films.

We discuss the other material and fabrication challenges faced, which include: 1. The high absorption of almost everything in the EUV. This means that only a few interfaces in a multilayer will contribute to its reflectance. 2. Surface contamination and corrosion. 3. The deposition on flight mirrors that are highly curved (f=0.8).

Introduction

The mirror coatings that we describe were prepared for the Extreme Ultraviolet Imager (EUVI), which is one of about four observational components of the IMAGE Mission, which is scheduled for launch February 2000. IMAGE, which stands for Imager for Magnetopause-to-Aurora Global Exploration, is a NASA funded Medium Explorer (MIDEX) program under the direction of principle investigator J.L. Burch of Southwest Research Institute.

The Extreme Ultraviolet Imager is designed to study the distribution of cold plasma in Earth's plasmasphere by imaging the distribution of He^+ ions through their emission at 30.4 nm. (Sandel, 1999) The He^+ 30.4-nm emission is a natural choice for remote sensing of the plasmasphere. Apart from H^+, which has no optical emission, He^+ is the most abundant ion in the plasmasphere. Typical peak densities are around 1000 cm^{-3}, and the He^+ ion constitutes roughly 20% of the plasma population. The He^+ outside Earth's shadow resonantly scatters solar 30.4-nm radiation, so that the plasmasphere glows at this wavelength. Because the plasmaspheric He^+ emission is optically thin, the integrated column density of He^+ along the line of sight through the plasmasphere is directly proportional to the intensity of the emission. Therefore measurements are relatively easy to interpret; its brightness is directly

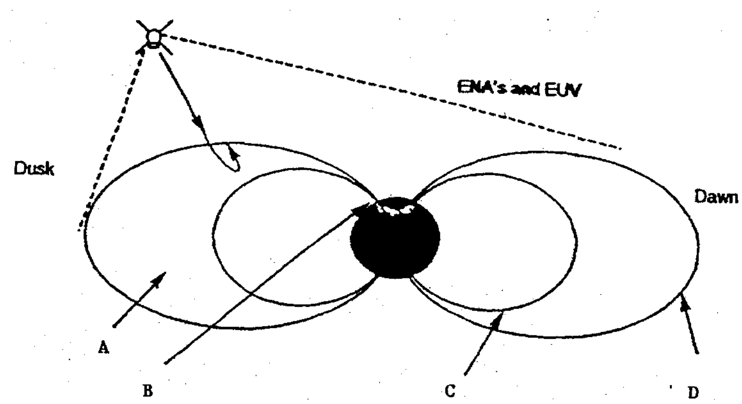

Figure 1. View of the IMAGE satellite relative to the Earth. A. Detached plasma region, B. Simultaneous Auroral Image, C. Plasmapause (disturbed times), D. Plasmapause (quiet times).

proportional to the He^+ column abundance. There is no need to consider the complication of radiative transfer effects. In addition, the He^+ 30.4-nm feature is easy to measure because it is the brightest ion emission from the plasmasphere, it is spectrally isolated, and the background is negligible. In principle a combination of a multilayer mirror manufactured with reflectance peaked at 30.4 nm and the appropriate filters to block lines far from the peak could produce a clean image.

Imaging the plasmasphere is the ideal means of monitoring changes in plasma density and distribution. IMAGE will be the first mission to provide full-plasmasphere images from outside the plasmasphere. The power of global imaging of the plasmasphere has been recognized for several years (Williams, 1990, Sandel, 1993). EUVI will address questions related to the spatial structures and temporal variations in the distribution of He^+ in the plasmasphere, to contribute to the overall mission goals of a better understanding of the response of the plasmasphere to geomagnetic activity, the mechanisms affecting the formation of the plasmapause, and the origin and character of spatial structures in the plasmasphere.

True global imaging requires a wide field of view. Effective imaging of the plasmaspheric He^+ requires global "snapshots" in which the high apogee and the wide field of view of EUVI provide in a single exposure a map of the entire plasmasphere. EUVI consists of three identical sensor heads, each having a field of view 30° in diameter. These sensors are tilted relative to one another to cover a fan-shaped field of 84°(30°, which is swept across the plasmasphere by the spin of the satellite, imaging 3pi steradians). EUVI's spatial resolution is ~0.6° or ~0.1 RE in the equatorial plane seen from apogee. The sensitivity is ~0.16 count sec^{-1} $Rayleigh^{-1}$, sufficient to map the position of the plasmapause with a time resolution of 10 minutes.

We report here on the development of a new dual function multilayer mirror coating which was used for the IMAGE mission and the coating of six flight mirrors. Three were selected for flight; the other were held in reserve. We begin by summarizing the goals/requirements of EUVI that led to our setting the specifications noted below for the mirror coatings and the challenges in applying the coating. Other aspects of the design, testing and integration of the electrical, optical and mechanical components of EUVI, and the scientific goals of EUVI are well described in Sandel 1999.

To achieve its goals, EUVI must:

1. accommodate a maximum 30.4-nm brightness of ~10 R in the plasmasphere as well as the much brighter, localized ionospheric source,
2. measure emissions of 0.1 to 0.3 R in an integration time of 10 min.,
3. have a wide field of view to encompass the entire plasmasphere in a single "snapshot,"
4. reject bright contaminating emissions, such as hydrogen Lyman alpha (H Lyα) from the geocorona and interplanetary medium, and the He 58.4-nm line from the ionosphere. H Lyα was effectively blocked by aluminum filters over the annular apertures, but aluminum is mostly transparent above 15 eV so finding a way to block higher energy photons such as the 58.4-nm (21 eV) line was critical.

General Considerations

One of the consequences of the requirement that the reflectivity be high at 30.4 nm is that the mirror coating must necessarily be a multilayer, since no single material will reflect more than a few percent at 41 eV. Multilayers for the soft x-ray range have been well known for several decades. The multilayer which was required for EUVI was not typical for several reasons and in several ways:

1. The reflecting coating had to be broad band. The light for each of the cameras passes through one of four annular opening covered with an aluminum filter. The annular openings collimates the light so that only rays between 11 and 18 degrees from normal arrive at the detector. Nevertheless, this is a relatively broad range of angles. This entrance aperture consists of four segments that collectively form a nearly-complete annulus. In each of the four segment of the annulus is a filter that transmits the He 30.4-nm line, while excluding the bright geocoronal H Lyα line at 121.6 nm as well as other low energy emissions. Light reflected from the mirror is focused on a spherical MCP detector.

2. More critically, there was the question, what to do about the lower EUV? As mentioned above, the 30.4-nm feature is, in principle, relatively easy to-measure because: it is the brightest ion emission in the plasmasphere (He II 2p→1s), it is spectrally isolated, and the background at that wavelength is negligible. But, there is a bright emission at 58.4 nm (21 eV), which comes from neutral helium in the earth's ionosphere which also must be blocked. It is at too high an energy to be blocked by the

aluminum entrance filters, but at too low an energy to have negligible reflectance from most materials commonly used in EUV mirrors. The EUVI team determined that it was ill-advised to try to develop special filters for blocking 21 eV that would not also block 41 eV. We proposed instead the concept of developing a multilayer systems which satisfied two optical functions: high reflectance (target >20 %) at 41 eV but low reflectance (<2%) at 21 eV. These specifications were particularly challenging because multilayers that had been used before in this range necessarily contain elements which have higher single layer reflectances at 58.4 nm than at 30.4 nm. To meet these considerations the mirror must have low reflectance at 21 eV without loss of reflection at 30.4 nm.

3. The coating must be optically stable in air for long enough for the mirrors to be mounted and integrated with the rest of EUVI. We took this as a requirement that the mirror reflectivity at 30.4 nm not change more than 10% (two percentage points) when exposed to dry laboratory air for three weeks. The finished system is stored in flowing, dry N_2 while it awaits launch.

Optical stability is a challenge because of the serious consequences which arise from even relatively modest surface contamination and corrosion of the upper most layers. First row elements, especially carbon through oxygen, have much higher absorption over the 10 to 50 eV range. As few as 5 nm of an oil film or surface oxide can significantly change a mirror's reflectance. Some oxides are self limiting, others are not. Aluminum was rejected as the spacer layer for the IMAGE mirrors (Fennimore, 1999) in favor of amorphous silicon, in consequence of our concern that its oxidation might not cease. This is in spite of the fact that aluminum is more transparent than a-Si at 30.4 nm. We also found that the oxide which will form on the mirror had to be explicitly accounted for in the optical design, but we found this could be used to our advantage. Our computations indicated that the oxide of the high index (that is, the absorber) member of the absorber/spacer bilayer can enhance the peak reflectance of the multilayer over a stack ending with the spacer layer that is used to passivate the surface. This result was established experimentally. (Squires, 1999) We also found this first layer prevented the further oxidation of the multilayer.

4. The coating process must be capable of uniformly coating an optic which is highly curved. Since each camera maps out 30 degrees of arc, the primary mirror is dishlike (see Figures 2 and 3), its f number much less than 1. The radius of curvature of the mirrors is 13.53 cm and their outer diameter is 12.9 cm. The reader should also note that there is a 3-cm hole in the center of the mirror.

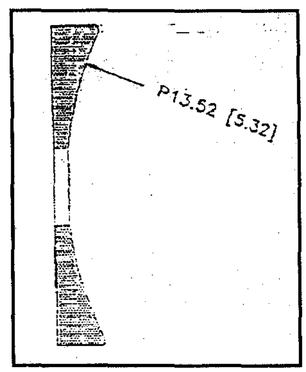

Figure 2. Side view drawing of the EUV mirror. The mirror has a diameter of 12.9 cm and a radius of curvature of 13.52 cm.

This was accomplished by tilting the mirror on its side so that the cord connecting the inner and outer edges of the mirror was roughly parallel to the surface of the 10 cm sputter guns. The mirror and holder were hung from a carousel and positioned so that about half of the holder would pass above the target. We achieved the required uniformity across the highly curved surface of the mirrors by rapidly rotating the mirrors in a specially constructed holder above the sputter targets and by masking the sputter target to block atoms coming from the side of the target closest to the inside of the chamber. The carousel conducted the spinning mirror in its holder sequentially from the uranium to the silicon guns and back to build up the desired multilayer structure. At any given instant only a sector of the mirror was above the sputter source. The mirror was spun rapidly on its axis so that in less than a second each part of the mirror, a given distance from the center, was exposed to the sputtering target for the same amount of time. We designed the appropriate masks by iterative deposition and XRD measurement cycles. Using these masks (see Figure 2 of paper 3767-55 in this proceedings) and carefully orienting the mirror holder, we produced coatings whose thickness varied by only about 1% from inside to outside (see Figure 4 curve 83).

Multilayer Design

In summary, the design requirements called for a mirror that had a high (>20%) reflectivity at 30.4 nm (He^+ 1s→2p) and low (<0.2%) reflectivity at 58.4nm (He 1s2→1s2p), both measured at 14.5 ± 3.5% to the surface normal. These specifications were challenging because most materials have much higher single layer reflectivities at 58.4 nm than at 30.4 nm. For example, the normal incidence reflectance of molybdenum at 58.4 nm is 24%. To reflect well at 41 eV and poorly at 21 eV, the top part of the stack which reflects well at 30.4 nm must act as an antireflection layer at 58.4 nm. Such mirrors with dual optical function in the extreme ultraviolet have not previously been designed or built. Because of the procedures established for the installation of the mirrors and their likely future environments we also decided that the mirrors must be optically stable in dry air for at least three weeks.

Initial Design Approach

The spacer layer was rather traditional. Transparency at both of the wavelengths was the issue, the best elements are aluminum and silicon. Aluminum was studied first but silicon replaced it when it became apparent that oxidation was an important issue. The high Z (high atomic number) layer we considered in depth was uranium. We considered uranium as the high Z layer because its indices at 30.4 and 58.4 nm are significantly different compared to other elements in the EUV.

Our initial analysis gave us confidence that this design requirement could be met with a periodic multilayer mirror consisting of a combination of an absorptive layer and a relatively transparent layer. The fact that the wavelength of 58.4 nm was about twice that at 30.4 nm gave us hope that we could find a layer thickness that would give us constructive interference between layer-pairs at 30.4 nm and destructive interference at 58.4 nm. Computation indicated that uranium could produce the required reflectances at 30.4 and 58.4 nm. Incidently, computation indicated the typical high Z metals used for multilayers or reflectors, such as molybdenum, tungsten, or platinum, are unsuitable for obtaining low reflectance at 58.4 nm. Typical computed reflectances of multilayers containing these metals are 8 to 10%.

The path to get to this relatively simple design was anything but straightforward. We developed and used a variety of computational tools to model the reflectance of multilayers composed of many possible material combinations. These included incorporation of the genetic algorithm (GA) (Lunt and Turley, 1999a; Lunt, 1999); to optimize material selection and layer thicknesses for best performance. The optimization was done by maximizing the merit function:

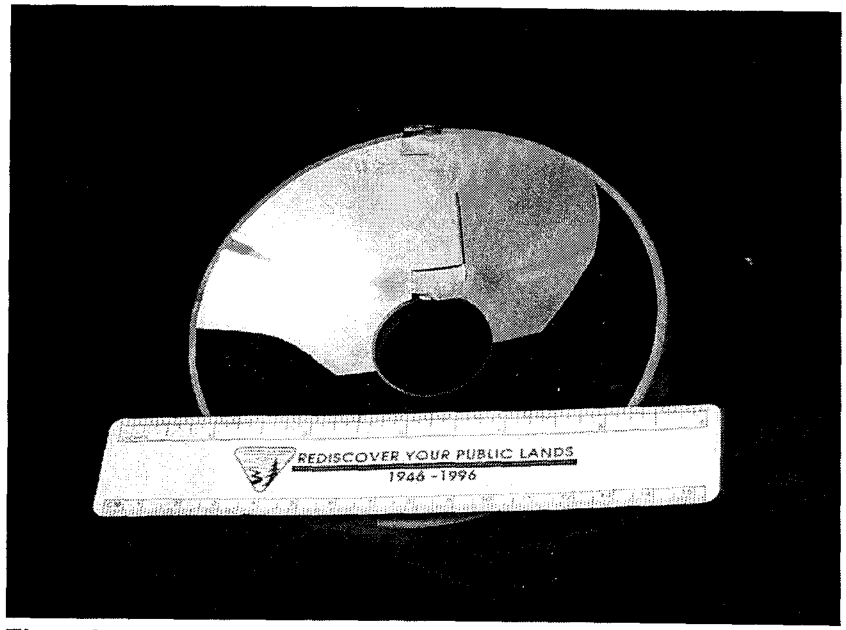

Figure 3. Pictures of a coated test mirror.

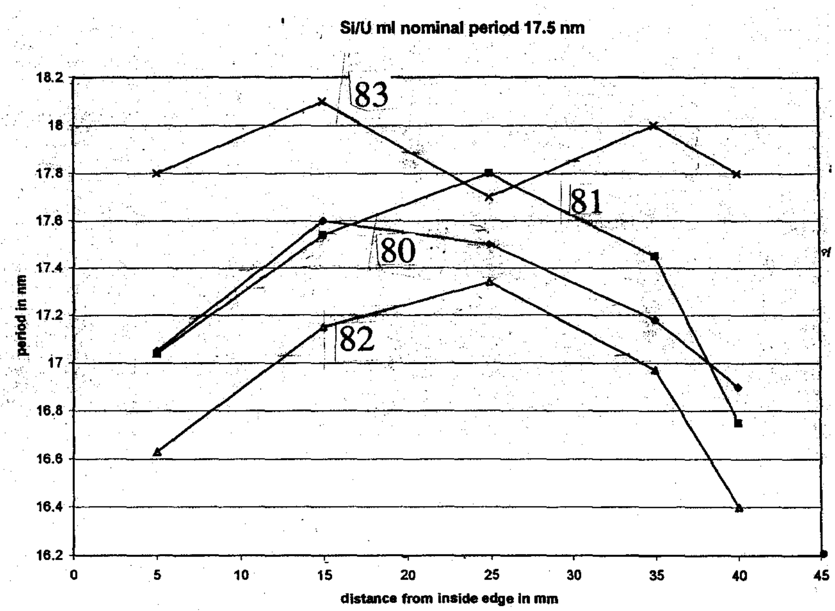

Figure 4. Uniformity: The multilayer period as a function of distance from the inisde edge of the mirrors as measured by XRD on Silicon wafer flats. The tilt angle of the spindle spinning the mirrors is 16.4 degrees from normal. The deposition times were the same for all four multilayers. As can be seen the period falls off at higher radii for 80,81,82. Most of this decrease is removed (sample 83) when the outer edge of the mask is cut off.(see Figure 2 of Squires 1999).

$$Merit = \frac{R_{304}}{\max(0.2, R_{584})}$$ where R584 is the reflectance at 58.4 nm and R304 the reflectance at 30.4 nm.

The utility of Genetic Algorithms is worth noting. In brief, it:
a. codes materials and thickness as DNA sequence on a gene,
b. crosses the genes to give children genes and computes the degree to which the merit function is satisfied in deciding what the next generation will look like,
c. mutations are allowed and surprises are common. Uranium is favored by the genetic algorithm but so was $Y_2 0_3$, which was not expected. (Lunt, S.) The reader is also invited to visit XUV.byu.edu where we plan to provide GA computations for remote users over the Internet. The work is by Spencer Olson.

The optimizer permitted design of fully aperiodic multilayer coatings. The additional degrees of freedom over a periodic design permitted us to design mirrors with better predicted performance, especially in achieving low 58.4-nm reflectance. We chose the genetic algorithm for this design because it allowed optimization with discrete variables (the choice of materials), provided a search for a global minimum, and was simple to constrain. Details about the genetic algorithm and these design efforts can be found in Lunt and Turley (1999b) and Lunt and Turley (1998).

Uranium, which had been identified early as a leading candidate for 30.4 nm, also proved to be the only metallic material for the high index layer which was also suitable for producing a multilayer for low 58.4-nm reflectance. The highest predicted reflectivity using the genetic algorithm was for an aperiodic $Y_2 0_3$/Al mirror. In the end, we did not use the aperiodic design in our final fabrication. Changing the thicknesses of the aperiodic stacks from layer to layer made it difficult to characterize them using x-ray diffraction. Without these growth diagnostics, we found it too difficult to optimize the stacks empirically during growth. Fabricating $Y_2 0_3$/Al stack presented the additional complication of requiring RF sputtering rather than DC magnetron sputtering because $Y_2 0_3$ is an insulator. The GA, on the other hand, provided us the direction we needed to try by suggesting oxidized uranium as the top layer material and showed us the proper range of thicknesses to consider.

Final Design Structure of Multilayer Coating

From top to bottom the flight mirror coating consisted of:
1. A thin layer of UO_x produced by oxidation of 1.5 nm of uranium within a few minutes of exposure to air. If the film oxidizes to UO_3 the top uranium layer will swell to over three times its original thickness. This oxide functions as the top high index layer in the multilayer when considering high reflectance at 30.4 nm. This is the first time this has been done for XUV multilayers. The oxide is also largely responsible for the low reflectance at 58.4 nm.
2. Six and a half periods of bilayers with 12.8 nm of silicon and 5.3 nm of uranium.
3. A bottom layer of 10.6 nm layer of uranium. This was twice the uranium thickness used in the other layers. This extra-thick bottom layer allowed the multilayer coating to be released with agua regia from the glass if recoating was necessary without compromising the smoothness and optical figure of the mirror blank.

Our final design also differed from the optimized initial designs because the latter designs did not account for factors which significantly changed the reflectivities. These factors included:
1. The models assumed the boundaries between layers were smooth and abrupt. While the roughness was probably less than 0.5 nm rms, the diffusion of Si into the U layers may have been as deep as 5-10 nm.
2. The optical constants for sputtered U in this region are uncertain.
3. Oxidation of the multilayers may have occurred during and after growth. Oxygen is highly absorbing in the XUV, and also affects the density and thickness of the layers.

Experimental evidence for each of these contributions is discussed further elsewhere (Fennimore, 1999, Fennimore, 1998, Squires, 1999).

Multilayer Mirror Fabrication

All films were deposited by DC magnetron sputtering. The uranium (U-238) target was depleted uranium bought from Manufacturing Sciences (Oak Ridge, TN). The 4-inch diameter, heavily doped silicon target was purchased from CERAC. The sputtering was done in a chamber evacuated to a base pressure of less than $3x10^{-6}$ torr with a Cryotorr 8 cryopump. The chamber was then backfilled to a pressure of $2.8x10^{-3}$ torr with ultrahigh purity (99.999% pure) argon passed through an UltraPure (NuPure Corporation) line filter which removed residual N_2, O_2, H_2O, and H_2. A plasma was generated in the argon by applying a potential (about 400 V for U and 550 V for Si) between the target and dark space shield. A magnetic field confined the plasma to the area near the target. Argon ions striking the target sputtered U or Si atoms from the surface. These accumulated on the mirror surface at a rate that was calibrated by x-ray diffraction (XRD) measurements on test samples.

We used small silicon wafer flats for trial depositions to prepare for coating the mirrors and as witnesses pieces that we coated simultaneously with the flight mirrors. These have coatings with the same thickness as the mirrors. Other flat trial samples were coated independently of the flight mirrors. The trial and witness samples were used to characterize the multilayers using XRD, atomic force microscopy (AFM), Auger electron spectroscopy (AES) depth profiling, and transmission electron microscopy (TEM). Based on our AFM and TEM (Fennimore, 1999) measurements on similar multilayer samples consisting of U/Al stacks, we expect the rms roughness of the layers to be about 0.5 nm.

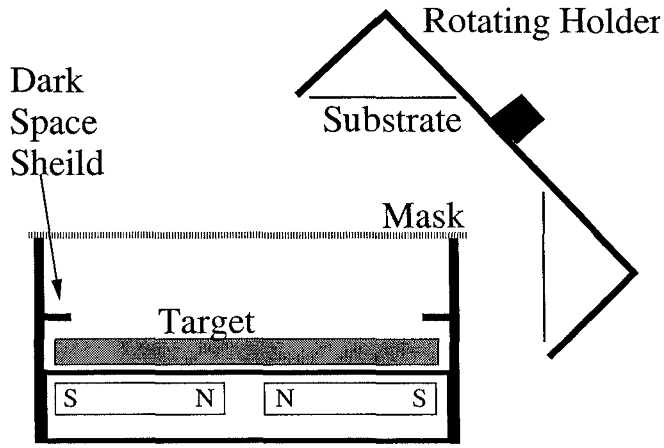

Figure 5. Schematic of rotating sample holder relative to sputter gun (size and angle are not to scale).

From the results of AES measurements on trial U/Al samples (Fennimore, 1999) we concluded that significant oxidation occurred in the top layers of the stack, and that there may be oxygen between layers in the stack. We added a UO_x cap to the production mirrors to reduce this problem.

The AES measurements of the U/Al samples also suggest the possibility of significant diffusion of Si into the U layers of the U/Si stack. Our experiments with chemically etching the coatings from the mirrors using aqua regia (a mixture of HCl and HNO_3) showed that the thickness of the bottom layer of uranium needed to be greater than 10.0 nm for the etching to work. The required thickness of the release layer provides secondary evidence that silicon diffuses into the first 5.0-10.0 nm of the underlying uranium.

Because even depleted uranium is naturally radioactive, we computed the rate of particle emission from the uranium in the mirrors and compared it to expected ambient backgrounds. Measurements were also made of the sensitivity of the MCP detector to radiation from the mirrors. Particle-induced MCP signals are comparable to the measured intrinsic dark count rates of the detectors.

Multilayer Mirror Testing

The reflectivities of the flight mirrors at 30.4 and 58.4 nm were measured within hours of their fabrication. The measurement system consisted of a McPherson 629 hollow cathode source filled with He and connected to a McPherson Model 225 1-meter scanning monochromator. Typical operating conditions for the hollow cathode source were a base pressure of 2×10^{-6} torr, He pressure of 0.35 torr, and a current of 0.25 amps. The operating pressure in the monochromator was kept below 10^{-4} torr. The monochromator used a Pt-coated grating blazed for 42.0 nm at near-normal incidence.

Using an atomic source with a monochromator gave us radiation limited only by the line widths of the spectral lines (<<0.1 nm) from the source. Our measured line widths were limited by the achievable monochromator resolution (about 0.025 nm). Since the light was incident on the monochromator and mirrors near normal incidence, we assumed it was unpolarized. Radiation from the monochromator was detected with one of two detectors. The first was a cooled back-thinned CCD camera from Princeton Instruments. It had a 1.25 cm^2 square sensitive area with 512 x 512 pixels. The camera gave us a measure of the spatial uniformity of the beam from the monochromator and of the spatial resolution of our system. The flux from the source varied by about a factor of two over the size of the spot. A given area of illumination would vary by 10% to 20% in intensity over time periods of tens of minutes. The second detector, an Amptektron MD-501 channeltron assembly, was used for quantitative measurements of intensity. Its relatively small detection area sampled a spatially uniform portion of the beam detected by the CCD camera. Typical measurements had a signal to noise ratio of several thousand.

Absolute reflectivity measurements were made on a flat reference mirror by measuring its signal from the channeltron detector at an equal distance from the monochromator with and without reflecting from the reference mirror. This process was repeated several times for each wavelength to enable us to compensate for any long-term drifts in the source intensity. The reflectivity of the flight mirrors were measured relative to the reference mirrors in a chamber where radiation reflected from either one could be measured within minutes of each other. The comparisons were made several times over periods of 30-60 minutes to enable us to account for any long term drifts in the source intensity.

In addition to the reflectivity measurements at BYU, we also measured the reflectance of flats in the LBL EUV calibration facility at wavelengths of 30.4 and 58.4 nm. For these measurements, the reference detector was facing anti-parallel to the beam, and located on the optic axis with the apex of the channeltron cone near the focal point. The mirror and reference detector were fixed in position relative to one another and were scanned as a unit to trace the 4-mm diameter beam along two perpendicular diameters. At all points in the scan, the beam remained parallel to the optical axis of the mirror, so the angle of incidence varied from 8° at the inner edge to 26° at the outer edge of the mirror. We assessed the background count rate in the reference detector by noting the response when the test beam passed through the central hole in the mirror. This background rate was about 1% for the 30.4-nm measurements and 15-20% for the 58.4-nm measurements. We cross-calibrated the reference detector against the continuous monitor between each mirror. This required repositioning the reference detector to face into the input beam.

Discussion

The final mirror design is noteworthy for a number of reasons:

1. The surface tarnish it essential for the optical performance. Figures 18-25 of Squires (1999) show the reflectance at 14.5° from normal for a large number of multilayer mirrors. As the discussion makes clear the top part of the stack which reflects well at 30.4 nm acts as antireflection layers at 58.4 nm. It increases the reflection 2% points at 30.4 nm, and it more than halves the reflectance at 58.4 nm. That decrease in reflectance is beyond what theory allows at 58.4 nm. Uranium oxide optical constants must be drastically different at 21 eV than previously computed using density weighted atomic scattering factors which is a standard method for obtaining optical constants in the EUV and x-ray range. We conclude, therefore, that chemical bonds are important in the lower EUV. Structure is also important as is shown in a companion paper in this volume (paper 3767-55 by M. Squires).

2. The multilayer is strictly periodic after the first layer. We thought we would need aperiodic. In the past, multilayers usually have consisted of periodic bilayers. Members of our group have explored turning from the standard periodic designs to aperiodic mirrors. These were the only ones that had the desired low R at 58.4 nm but UO_x provided low reflectance without significant use of aperiodic designs. For the flight mirrors we used the top uranium tarnish layer which naturally forms on such multilayers, in a few seconds in air as an intrinsic part of achieving high 30.4 and low 58.4-nm reflectance.

Conclusion

1. We have developed a new family of EUV multilayer mirror coatings using uranium. Using this approach we have coated a set of six mirrors for the EUV Imager, a component of the IMAGE mission.
2. The mid to lower EUV is qualitatively different that the x-ray in designing and fabricating multilayer reflectors. In particular first row elements and compound have as strong an optical effect as high Z metals have. In contrast with the soft x-ray range where it can be shown that pure metal is always better from an optical point of view.
3. Obtaining better optical constants for this range is high priority.
4. We have developed tools for multilayer calculations for the EUV.

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References

Sandel, B. R., et al.:1999, 'The Extreme Ultraviolet Imager Investigation for the IMAGE Mission,' prepared for Space Science

Reviews

Williams, D. J.: 1990, in B. Hultqvist and C. G. Falthammer (eds.), 'Magnetospheric Physics', Plenum Press, New York, pp. 83-101

Sandel, B. R., Drake, V. A., Broadfoot, A. L., Hsieh, K. C., and Curtis, C. C.:1993, Remote Sensing Reviews, 8, 147.

Fennimore,A., Allred, D., Turley R., Vazquez, C., and Chao, B.:1999, 'Morphology and oxidation of U/Al and UN/Al EUV multilayer mirrors,' submitted to Applied Optics.

Squires M. B.:1999, 'On determining the optical constants of sputtered U and a-Si at 304 and 584 Å ,' BYU Honors Thesis.

Lunt, S. and Turley R. S.:1999a, 'A tool for EUV mirror optimization,' submitted to Proc. Utah Acad.

Lunt S.:1999, 'The use of genetic algorithms in multilayer mirror optimization,' BYU Honors Thesis.

Lunt, S. and Turley R. S.:1999b, 'Designing bifunctional XUV mirrors for 304 and 584 Å ,' submitted to J. X-Ray Sci. and Tech.

Lunt, S. and Turley R. S.:1998, Physics of X-Ray Multilayer Structures. 4.

Fennimore, A.:1998, 'Morphology and oxidation of U/Al and UN/Al multilayer mirrors,' BYU Honors Thesis.