VUV bandpass reflective coatings for the SMILE-UVI instrument

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ABSTRACT

The Ultraviolet Imager (UVI) is one of the instruments of the ESA-CAS Solar wind Magnetosphere Ionosphere Link Explorer (SMILE) joint mission to image Earth's northern auroral regions over the 160-180 nm UV waveband with a 10° × 10° field of view. The UV light is guided to the detector with four thin film-coated mirrors that ensure most of the signal filtering, crucial to achieve a high out-of-band rejection and limit contributions from solar diffusion, dayglow and unwanted atomic spectral lines. In this paper, we present the design and performances of the spectrally selective reflective coating, which is based on an interferential MgF2/LaF3 multilayer stack deposited by ion-assisted electron-beam evaporation. Its peak reflectivity is above 85% and with an adjustable central wavelength within 1 nm, whereas the out-of-band reflectivity between 120 nm and 155 nm and between 200 nm and 1100 nm remains below 6% on average. The coating has been space qualified (thermal cycling under vacuum, radiations, UV exposure…) and shows stable performances in conditions representative of the instrument operation environment.

Keywords: SMILE, interferometric coating, VUV, reflective coating, ebeam

1. INTRODUCTION

The Solar wind Magnetosphere Ionosphere Link Explorer (SMILE) is a joint mission by ESA and CNSA aimed at studying the interaction between the solar wind and Earth's magnetosphere. SMILE carries four key instruments to investigate the coupled solar wind–magnetosphere–ionosphere system: the Light Ion Analyzer (LIA), the MAGnetometer (MAG), the soft X-ray Imager (SXI), and the UltraViolet Imager (UVI).

The UVI is an ultraviolet camera designed to capture images of Earth's northern auroral regions, providing insights into the link between magnetospheric processes, observed by the SXI, and the behavior of particles in the ionosphere. The system uses a four-mirror on-axis design with a CMOS sensor and light intensifier, achieving 150 km spatial resolution at apogee and a 10° × 10° field of view. It focuses on the 160-180 nm wavelength, part of the Lyman-Birge-Hopfield (LBH) N_2 band. One of the main challenges for UVI is filtering out visible sunlight to observe auroras continuously. To maintain an adequate signal-to-noise ratio, a high rejection of visible light (1E-8 to 1E-9) is required, achieved in part by a specific filter coating on the optical surfaces.

This work presents the performances of a multilayered VUV interferometric reflective coating developed for UVI to reject unwanted light outside the 160-180 nm wavelength range

2. MULTILAYER COATING PERFORMANCES

To achieve the desired performance, we rely on an interferometric coating based on a modified π-multilayer design. By carefully selecting materials and adjusting the thickness of the thin film layers, the peak reflectance position and bandwidth can be precisely controlled while maintaining the necessary rejection ratio. In these π-multilayer coatings [1][2], alternating layers of materials with contrasting refractive indices create the interference effect. MgF_2 and LaF_3 were chosen as the coating materials due to their high refractive index contrast and low absorption, which preserves the coating's high throughput.

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The four UVI mirrors on SMILE, made from N-BK7, vary in shape: two are concave and two are convex, with diameters ranging from 70 mm to 120 mm and radii of curvature between 175 mm and 272 mm. The surface roughness is below 0.5 nm RMS on the clear aperture and remains under 1.2 nm RMS after coating. Each mirror is coated individually using assisted e-beam evaporation, along with a flat N-BK7 witness sample at the center for spectroscopic characterization. Pre-calibration ensures coating uniformity across both the witness sample and the mirror's clear aperture. The coatings are optimized for incidence angles between 10° and 22.3°.

Figure 1 shows the reflectance of the coating on a 2 mm-thick N-BK7 substrate at a 10° incidence angle. The out-of-band response above 250 nm is increased due to reflection from the smooth substrate backside, absent in the diffusive mirror backside. Estimates suggest this accounts for approximately half of the reflectance at 400 nm seen in the right panel of Figure 1. The high reflectance peak (above 85%) can be finely tuned within 1 nm by adjusting the layer thicknesses. Figure 2 illustrates the angular dependence of the reflectance spectra for angles of 10°, 14°, and 23°, which are relevant to the UVI instrument.

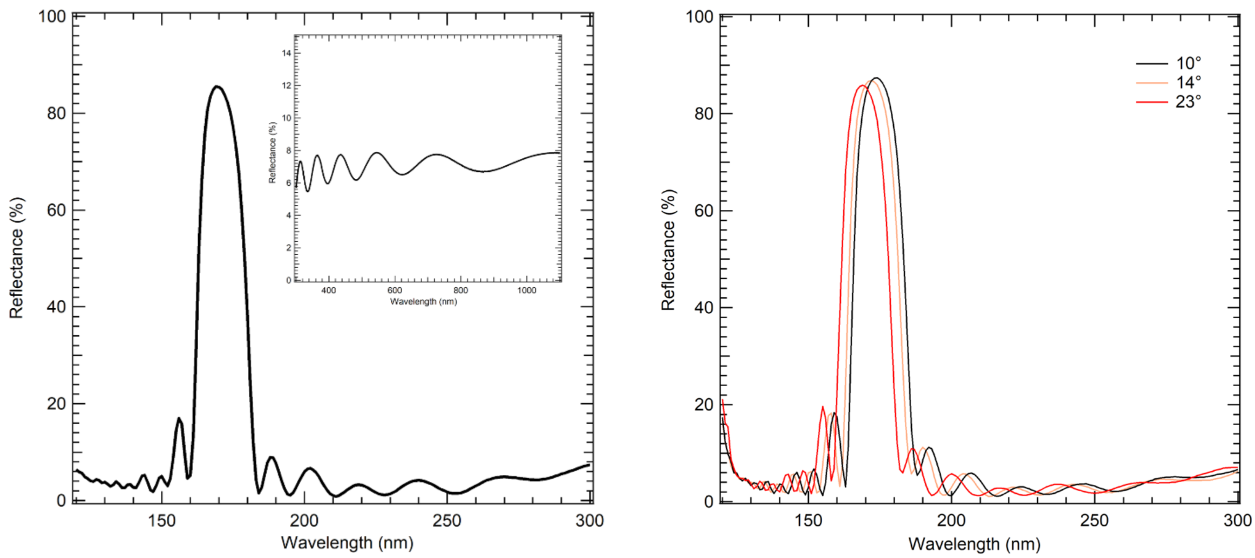

Figure 1: Reflectance of a coated N-BK7 substrate at a 10° incidence angle, shown between 120 nm and 1100 nm (left panel), including the contribution from the substrate's backside. The angular dependence of the coating reflectance is shown in the right panel.

3. COATING QUALIFICATION

The coating selected for the SMILE mission has undergone a comprehensive qualification campaign, designed to simulate the conditions it will face throughout the mission's lifetime. Coated samples were prepared and subjected to various environmental tests, including solvent immersion, thermal humidity exposure, thermal cycling in a vacuum, proton irradiation, and UV exposure. A summary of these environmental tests is provided in Table 1.

Table 1. Description of the environmental tests performed during the SMILE qualification campaign.

Environmental test	**Conditions**
Immersion in solvents	10 min in chloroform, acetone, ethanol
Humidity resistance test	24 h at 45 °C, 93 % of relative humidity
Thermal vacuum cycling	1E-6 mbar, 25 cycles, –87 °C to 53 °C, 25 min dwell time

Proton irradiation	70 Mrad, 10 MeV, 1.6E8 protons/cm²
UV exposure (vacuum)	1E-5 mbar, 22.5 kcal/cm², acceleration factor ×12

The impact of the tests on the coating integrity is evaluated through visual inspection of the samples, while optical performance is assessed via spectral reflectivity measurements across the 120-1100 nm wavelength range. A summary of these verification tests is provided in Table 2. The criteria for success after testing are as follows: the coating must maintain a uniform appearance, showing no discoloration, stains, streaks, smears, haziness, or signs of intrinsic damage. Additionally, there should be no flaking, peeling, blistering, cracks, or delamination. Reflectivity should remain unchanged within a measurement accuracy of ±1%, except for proton irradiation, where a degradation of up to 1% (±2%) is acceptable.

Table 2. Description of the verification tests performed during the SMILE qualification campaign.

Verification test	**Conditions**
Visual inspection	Binocular ×1 and ×20
Reflectance measurements	120–1100 nm, VUV and UV–VIS–NIR spectrometers
Adhesion test	Tape removal, 2 – 3 s/25 mm

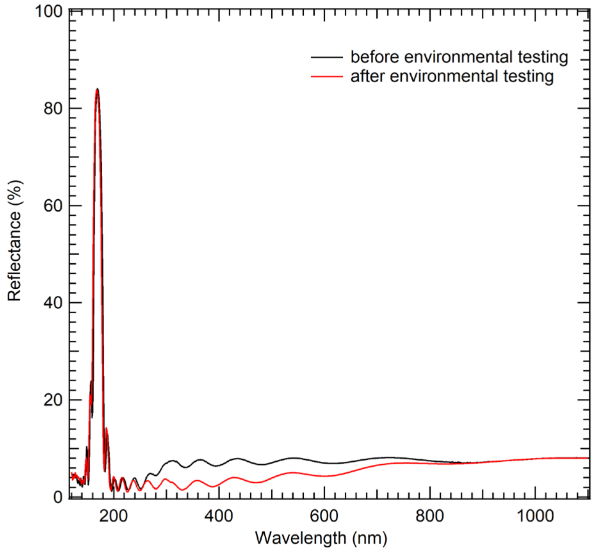

Figure 2: Reflectance of a coated N-BK7 substrate at a 10° incidence angle, shown both immediately after coating (black) and following all environmental tests (red).

Figure 2 compares the full reflectance spectra of a qualification sample before and after the complete environmental testing campaign. Following proton irradiation, the N-BK7 substrate showed a color change from transparent to yellow; however, this did not affect the overall performance of the coating. Apart from the influence of the substrate after irradiation on the out-of-band response, only minimal differences were observed. The coating passed all qualification tests, though caution is advised with humidity exposure due to the presence of hygroscopic materials in the coating.

4. CONCLUSION

In conclusion, we successfully developed a high-throughput reflective coating that meets the stringent filtering requirements of the UVI instrument for the SMILE mission. The coating achieves over 85% reflectivity, with the peak wavelength adjustable within 1 nm, while maintaining an out-of-band reflectance below 6% on average. This interferometric coating has been fully qualified for the environmental conditions expected during the SMILE satellite's mission.

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