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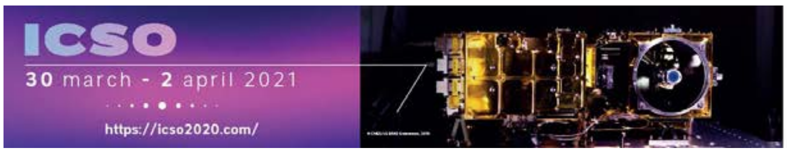

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Test of protected silver coating on aluminum samples of ARIEL main telescope mirror substrate material

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ABSTRACT

Ariel (Atmospheric Remote-Sensing Infrared Exoplanet Large Survey) has been adopted as the M4 mission for ESA "Cosmic Vision" program. Launch is scheduled for 2029.

ARIEL will study exoplanet atmospheres through transit spectroscopy with a 1 m class telescope optimized in the waveband between 1.95 and 7.8 µm and operating in cryogenic conditions in the temperature range 40-50 K.

Aluminum alloy 6061, in the T651 temper, was chosen as baseline material for telescope mirror substrates and supporting structures, following a trade-off study. To improve mirrors reflectivity within the operating waveband and to protect the aluminum surface from oxidation, a protected silver coating with space heritage was selected and underwent a qualification campaign during Phase B1 of the mission, with the goal of demonstrating a sufficient level of technology maturity.

The qualification campaign consisted of two phases: a first set of durability and environmental tests conducted on a first batch of coated aluminum samples, followed by a set of verification tests performed on a second batch of samples coated alongside a full-size demonstrator of Ariel telescope primary mirror.

This study presents the results of the verification tests, consisting of environmental (humidity and temperature cycling) tests and chemical/mechanical (abrasion, adhesion, cleaning) tests performed on the samples, and abrasion tests performed on the demonstrator, by means of visual inspections and reflectivity measurements.

Keywords: 1-m class space telescope, infrared optics, aluminum mirrors, protected silver coating, coating environmental tests, reflectivity measurements

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1. INTRODUCTION

Ariel has been recently adopted as ESA Cosmic Vision Program M4 mission. In its 4-year nominal mission, Ariel will conduct a survey of known exoplanets to characterize their atmospheres through transit spectroscopy in the wavelength band between 0.5 µm and 8 µm.

The Ariel telescope is based on an off-axis, unobscured Cassegrain design with an elliptical primary mirror with an aperture of 1100 mm (major axis) and 768 mm (minor axis) and a light collecting area of approximately 0.6 square meters. Telescope performance is diffraction limited at the wavelength of 3 µm on a 30" Field of View. The required average telescope throughput is 96%[1,2]. Telescope and instruments will operate at a temperature below 50 K.

Following the heritage of the JWST MIRI instrument[3], aluminum alloy 6061-T651 has been chosen for mirrors substrates and supporting structures of the telescope, after a trade-off study[4] on manufacturability and cost.

To protect the mirrors and to improve their reflectivity in the visible section of the operating waveband, a protected silver coating with space heritage from CILAS[‡] was chosen as baseline.

Although several examples of cryogenic silver-coated aluminum mirrors are found in literature[5–7], the large size of the primary mirror and its curvature raised concerns on the uniformity of the deposition process and stability of the coating.

An initial study was therefore devised to test optical performance and durability on Al6061-T651 substrates, consisting of a qualification campaign on coated aluminum samples[8], and a verification test on additional samples and on a full-scale demonstrator of Ariel primary mirror denoted PTM.

This paper describes the verification tests, in particular the evaluation of coating performance and durability by means of adhesion tests, reflectivity measurements and environmental tests.

2. MATERIALS AND PROCESSES

2.1 Items Under Test

The coating verification tests were performed on the following items coated together in the same run:

1. the PTM (Figure 1), a spherical mirror with a radius of curvature of 2401 mm and an elliptical optical aperture of 1100 x 730 mm, cut from a rolled plate of Al 6061-T651, the current baseline for Ariel telescope mirrors and supporting structure;
2. 6 aluminum samples, shaped as disks 6 mm thick 25 mm in diameter, obtained from the same plate from which the PTM substrate had been cut (Figure 2 shows one of the samples being held for visual inspection before the coating run);
3. 2 sets of glass samples measuring 25 mm and 48 mm in diameter respectively to serve as reference for spectral reflectivity and for the profilometry measurements.

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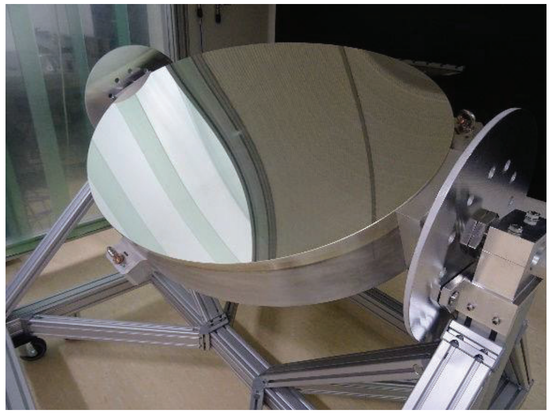

Figure 1. Picture of the PTM mirror mounted on its transport and handling trolley before coating (courtesy of CILAS).

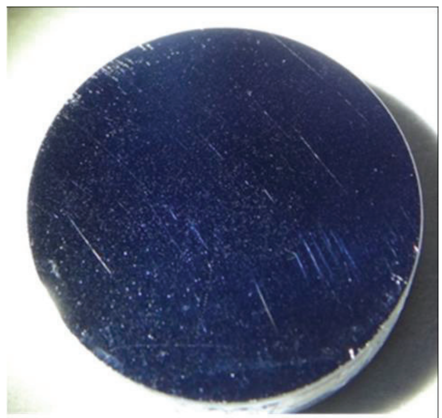

Figure 2. Picture of an aluminum sample used for the qualification during a visual inspection before being coated (courtesy of CILAS).

The roughness of the optical surface on the aluminum samples was measured with a Taylor Hobson CCI White Light Interferometer with magnifications 10x and 50x. All samples measured roughness was within the 10 nm RMS specification.

The surface roughness of the PTM, measured at 10 different locations on its optical surface, was instead in the range 21.5–26.9 nm RMS.

The PTM and aluminum samples had been manufactured by MediaLario[§].

2.2 Coating Process

The coating process used by CILAS for this batch is based on physical vapor deposition. The items to be coated are laid on a tray that slides inside a large magnetron sputtering chamber, and moved back and forth beneath a set of cathodes, to minimize deposition inhomogeneities[9]. The process is suited to optical substrates up to 2 m by 2 m of footprint and 0.4 m of thickness[10].

[§] Media Lario S.r.l., Via al Pascolo, 23842 Bosisio Parini (LC), Italy

The protected silver coating employed for the study consists of three layers: a NiCr adhesion layer of less than 10 nm of thickness, the silver layer, and a dielectric capping and protection layer. The process had already been qualified on aluminum samples and produces a coating layer measuring on average 350 nm of thickness, with 10% uniformity.

The layout of the items on the coating tray is shown in Figure 3.

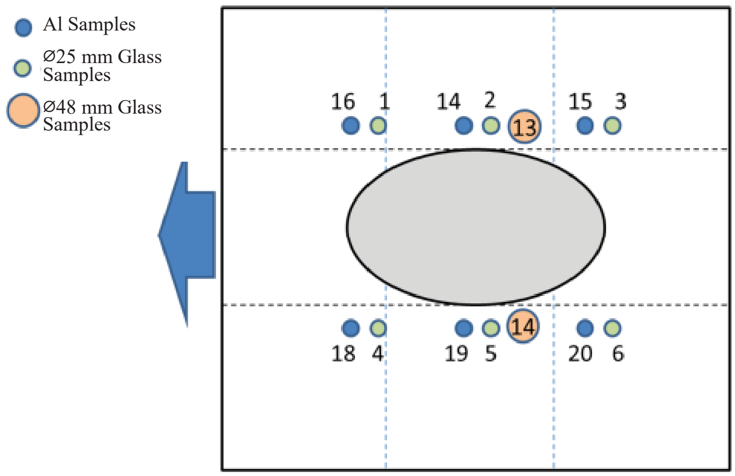

Figure 3. Layout of the items to be coated on the tray of the coating chamber. The blue arrow indicates the direction of insertion into the chamber.

3. VERIFICATION METHODS

The tests described in this paper have the purpose of verifying that the performance and durability of the protected silver coating deposited on the PTM are consistent with the results obtained during the qualification phase [8].

Four of the witness samples deposited together with the PTM were therefore subjected to a series of humidity, temperature, cleaning, abrasion and adhesion tests, evaluated by visual inspection and assessment of the variation of relative spectral reflectivity measurements taken before and after the set of tests.

Additionally, the coating thickness was measured on one of the glass samples, and the durability of the coating on the PTM was assessed through adhesion testing.

The following paragraphs describe the details of the verification methods employed.

3.1 Visual Inspection

Visual inspection was performed at CILAS on the optical area of each sample according to ISO standard 9211-4:2012[11].

Inspection of the PTM was performed both by CILAS and MediaLario.

3.2 Relative Reflectivity Measurements

Relative reflectivity measurements were performed at CILAS with a Perkin-Elmer Lambda 950 spectrophotometer with a reflectometry accessory in the waveband 500 nm–2500 nm and with an accuracy of ±0.6% from 500 nm to 890 nm and ±1% above 890 nm.

3.3 Humidity Test

The test was realized at CILAS according to ISO 9211-3:2008[12] Test #5 (damp heat). The samples were exposed to a 90% humidity environment at 55°C (+/-3°C) for 24 hours with a maximum temperature slope of 2°C/minute. No condensation was observed on the coated surfaces during the test.

3.4 Temperature Cycling Test

The samples were subjected to 30 cycles between -40°C and 70°C with a maximum temperature slope of 2°C/minute and a dwell time of 15 minutes. The test was performed at CILAS.

3.5 Cleaning Test

The test was performed at CILAS applying their standard cleaning procedure based on ethanol and acetone solutions, using an optical wipe. The test was repeated 5 times.

3.6 Abrasion Test

Test realized at CILAS on one sample, according to ISO 9211-4:2012[11], Test Method 01, Severity Level 01.

3.7 Adhesion Test

Adhesion tests were performed following ISO Standard 9211-4, Method 02, Severity 02[11].

Tests on samples were performed at CILAS with a cellophane tape, while the test on the optical surface of the PTM was performed at MediaLario using Kapton® tape strips.

4. TEST RESULTS

4.1 Environmental and Mechanical Tests

One aluminum sample was subjected to the whole sequence of chemical/mechanical tests (cleanability, abrasion and adhesion), while three other samples underwent the environmental set of tests (humidity and temperature cycling) and later the adhesion test. The two remaining aluminum samples have been kept as references for aging.

Results were satisfactory and in line with the outcomes from the coating qualification phase: no discernible signs of coating degradation nor delamination were apparent.

Reflectivity measurements did not highlight any change in performance either, as described in paragraph 4.2.

Adhesion tests on the coated PTM were performed on two separate areas of the mirror, and were also successful with no sign of coating degradation nor visually detectable traces of the coating on the tape strip (Figure 4).

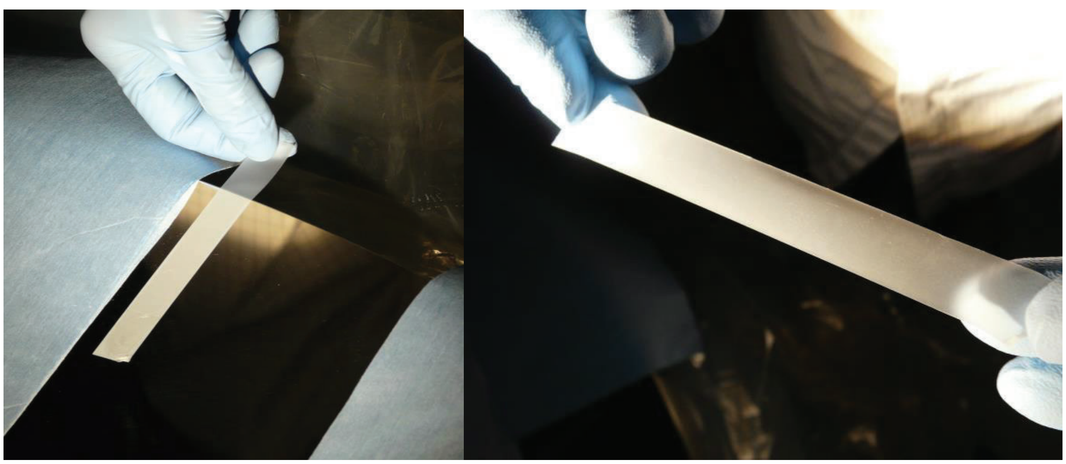

Figure 4. Adhesion test on the PTM mirror. On the left, the tape positioned perpendicular to the edge of the mirror right before lift-off. On the right, the sticky side of the tape after lift-off, showing no detached coating particles (pictures courtesy of MediaLario).

4.2 Reflectivity Measurements

Figure 5 illustrates reflectivity measurements of the samples that underwent mechanical (#18, 19, 20) and cleaning (#16) tests. Variations between measurements of the same sample are within the accuracy of the measurement instrument.

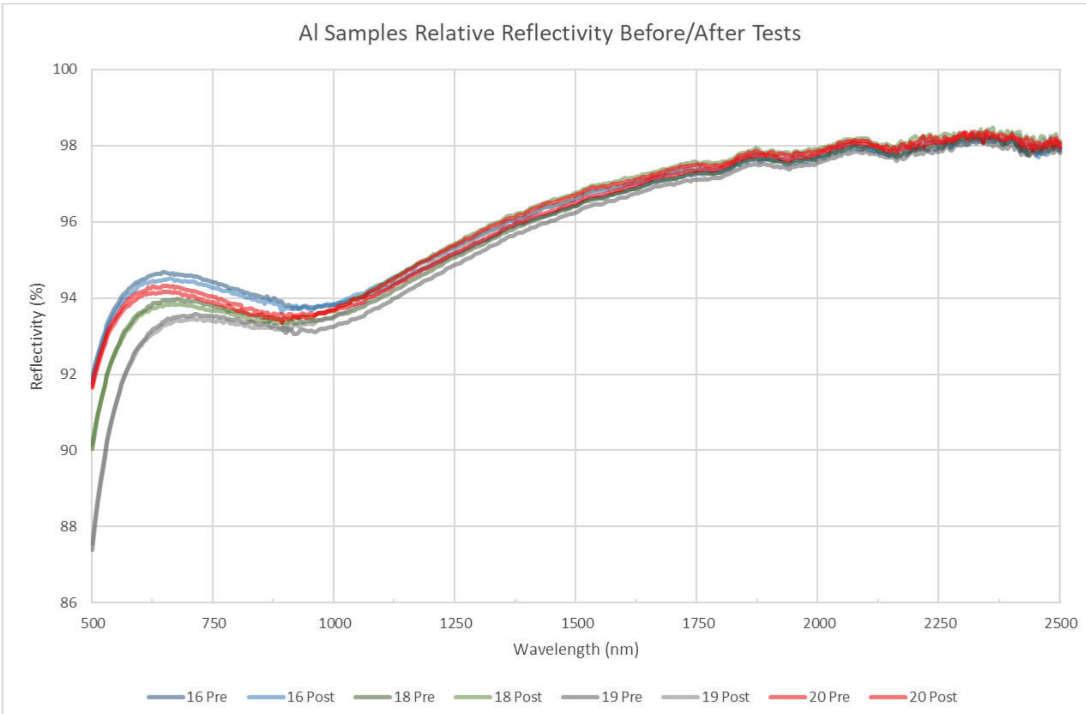

Figure 5. Reflectivity measurements of samples 16, 18, 19 and 20 before ("Pre" in the legend) and after ("Post" in the legend) the tests, showing no significant change.

4.3 Profilometry

Glass sample number 14 was partially covered with a mask during coating, and the depth of the resulting ridge was measured with a profilometer in two points. The resulting coating thicknesses were 342 nm and 345 nm, compatible with measurements taken during the qualification coating run at the same position in the coating chamber of 348 nm.

5. CONCLUSIONS

Following the successful qualification of the selected protected silver coating for the aluminum mirrors of the Ariel telescope, a coating test run was performed on the full size demonstrator of the telescope primary mirror (PTM), together with 6 aluminum samples, to further confirm performance and durability of the coating.

Results of adhesion, abrasion, cleaning, humidity and thermal cycling tests performed on the samples and verified by visual inspections and reflectivity measurements showed no alteration in appearance imputable to deterioration or delamination of the coating, nor a degradation in optical performance in the waveband 500–2500 nm.

Adhesion tests performed on the optical surface of the PTM further confirmed the durability of the coating.

These results were considered satisfactory and led to a successful termination of the coating qualification campaign.

Further measurements on the samples will be repeated periodically to assess possible aging deterioration.

6. ACKNOWLEDGEMENTS

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