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The primary mirror of the ARIEL mission: testing of a modified stress-release procedure for Al 6061 cryogenic opto-mechanical stability

P. Chioetto (1,2,3), V. Da Deppo (1,3), P. Zuppella (1,3), E. Pace (4), G. Morgante (5), L. Terenzi (5), D. Brienza (6), E. Diolaiti (5), M. Lombini (5), F. Cortecchia (5), N. Missaglia (7), G. Bianucci (7), G. Malaguti (5), G. Micela (8) and the ARIEL Team.
(1) CNR-Istituto di Fotonica e Nanotecnologie di Padova, Padova, Italy, (2) Dipartimento di Ingegneria dell'Informazione, Padova, Italy, (3) INAF-Osservatorio Astronomico di Padova, Padova, Italy, (4) Dipartimento di Fisica ed Astronomia – Università degli Studi di Firenze, Firenze, Italy, (5) INAF-Osservatorio di Astrofisica e Scienza dello spazio di Bologna, Bologna, Italy, (6) INAF-Istituto di Astrofisica e Planetologia Spaziali, Roma, Italy, (7) Media Lario S.r.l., Bosisio Parini (Lecco), Italy, (8) INAF-Osservatorio Astronomico di Palermo, Palermo, Italy.

Abstract

Atmospheric Remote-Sensing Infrared Exoplanet Large Survey (ARIEL) was selected as the ESA fourth medium class mission and is expected to launch in 2028. ARIEL is based on a 1 m class telescope optimized for spectroscopy in the waveband between 1.95 and 7.8 μm, and operating in cryogenic conditions in the range 50 – 60 K [1].

Aluminum alloy 6061 has been chosen as baseline material for the telescope after a tradeoff study. The large size of the main mirror however (0.6 square meters) presents specific production challenges concerning opto-mechanical stability in cryogenic applications.

To minimize risk, fabrication processes will first be tested on flat samples of 150 mm of diameter and then applied to a full-size demonstrator mirror, before finalizing the design and producing the flight mirror.

This paper describes testing and evaluation of the material stress release recipe that has been proposed for the mirrors. Preliminary results will also be presented, showing that the proposed treatment procedure has so far produced promising results.

1. Introduction

During the assessment phase of the ARIEL mission, an extensive material trade-off study was conducted to determine the baseline material for the whole telescope. Aluminum alloy 6061-T651 has been chosen as baseline material for its availability, cost effectiveness and lightweight characteristics [2]. Aluminum alloy mirrors are a popular choice for IR instruments, although precision mirrors larger than 0.5 m in diameter present specific production difficulties, in particular regarding dimension stability, that limit their adoption [3].

The telescope will be realized, mounted and aligned at room temperature. Since its parts are made of the same material, it is expected to scale down proportionally in cryogenic conditions without major alterations to its optical performance. Residual stress in the material can however introduce opto-mechanical instabilities that result in unpredictable and irreversible deformations during thermal cycling.

In order to minimize any risks associated with this material choice, a state-of-the-art thermal stress release procedure has been identified and will be tested on material samples of the primary mirror [4].

1.1. Material Samples

A total of seven material samples of the Al 6061-T651 will be used in the tests. Each sample consists of a cylinder of 150 mm of diameter and 19 mm of thickness. The mirror surface will be machined flat and then diamond turned within 100 nm RMS with a technology comparable to the one that will be used for the final flight mirror.

Each sample is marked on the back (non-optical surface) with a serial number, and laterally on the rim to ensure consistent azimuthal orientation between measurements.

2. Stress-release Procedure Details

The original stress-release procedure, described in [4], consists of several thermal cycles interspersed with the machining and polishing mirror fabrication steps. The procedure under test is a streamlined version as detailed below.

1. Age at 175 °C (8 hours).
2. Finish machining, leaving enough margin for SPDT/polishing.
3. Age again at 175 °C (8 hours).
4. Three thermal cycles from -190 °C to 150 °C with rates not to exceed 1.7 °C/min.
5. Diamond turning/polishing.
6. Three thermal cycles as in Step 4.

After every step of the procedure, surface error is measured and compared with the previous steps to assess form variations. After Step 4, the mirror substrate is supposed to have reached stability, so it will be machined to its final specifications and undergo a final verification thermal cycle to confirm surface form stability.

To validate the modified procedure, it will first be applied to the test sample, allowing us also to set-up the thermal cycling and measurement apparatus, and then replicated to the six additional samples for final validation.

3. Form Error Measurement Procedure

In order to assess substrate stability, each mirror surface will be measured with a Fizeau type interferometer before and after undergoing the last step of the stress-release procedure describe in the previous section.

Residual stresses are considered to be reasonably negligible, and thus not affecting stability when reaching operating cryogenic conditions, if the RMS form variation is within 60 nm ($\lambda/10$ at 632.8 nm).

Two sets of measurements will be taken, the first using a Wyko 6000 interferometer (6 inches aperture), available at the manufacturer's site, and the second using a Zygo® DynaFiz™ interferometer with a 4-to-6 inches Aperture Converter, available at the site where the cryogenic cycles are performed.

4. Preliminary Results

At the time of writing, the test sample mirror has undergone the stress-release procedure up to the last verification step.

Although we are still pending final results from the first test mirror, a comparison of the measurements taken before and after Step 4 shows a difference of 18 nm RMS and 291 nm PtV (Figure 1) on a mirror that is flat within 377 nm RMS and 1573 nm PtV (the mirror had not yet been diamond turned and polished at this phase). This preliminary result hopefully foretells a positive outcome for the testing campaign.

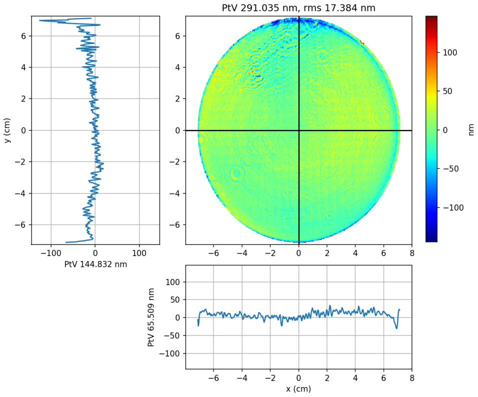

Figure 1: Difference of interferometric surface maps after and before thermal cycle Step 4. Maps have been acquired with MetroPro software and processed and visualized with Python scripts to reduce the effects of small misalignments between the two measurements.

5. Conclusions

ARIEL telescope optical performance at operating cryogenic conditions depends on dimensional stability of its aluminium alloy mirrors. This article illustrate preliminary positive results from testing a modified stress-release procedure to stabilize Al 6061-T651.

References

[1] Puig, L. et al., The Phase A study of the ESA M4 mission candidate ARIEL, Exp. Astron. 46-1, 2018.

[2] Da Deppo, V. et al., ARIEL telescope material Trade-off, ARIEL-INAF-PL-TN-004_2.0, 2017.

[3] Newswander, T. et al., Aluminum Alloy AA-6061 and RSA-6061 Heat Treatmentfor Large Mirror Applications, Proc. SPIE 8837, 883704, 2013.

[4] Ohl, R.G. et al., Comparison of Stress Relief Procedures for Cryogenic Aluminum Mirrors, Proc. SPIE 4822, 2002.