ARIEL Consortium Phase A Payload Study

ARIEL Telescope Material Trade-Off

ARIEL-INAF-PL-TN-004

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Prepared by: Vania Da Deppo (signature) Date: 15/02/2017

Vania Da Deppo (CNR-IFN PD/INAF)
G. Morgante, E. Pace
ARIEL Consortium System Team

Reviewed by: Date:

Kevin Middleton (RAL Space)
ARIEL Optical Lead

Approved & Released by: Date:

Paul Eccleston (RAL Space)
ARIEL Consortium Project Manager

DOCUMENT CHANGE DETAILS

Issue	Date	Page	Description Of Change	Comment
0.1				
1.0	01/06/16	All	Document updated by PE with quantitative assessment of options, criteria and conclusions. Document released for MCR.	
2.0	13/02/17	All	Tables and text updated according to MCR discussion – Document released for ESA MSR.	

DISTRIBUTION LIST

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	Manuel Gudel		Etienne Renotte		
	David Luz		Martin Frericks		
		Other Engineering Team			
		✓	*As necessary for doc*		

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1 PREAMBLE

1.1 SCOPE

This document describes the trade-off on the materials to be used for the ARIEL telescope. A discussion on the characteristics to be considered in the material selection is given.

1.2 PURPOSE

This document will allow to define the guidelines for the selection of the material for the ARIEL telescope mirrors and structure.

1.3 APPLICABLE DOCUMENTS

AD #	APPLICABLE DOCUMENT TITLE	DOCUMENT ID	ISSUE / DATE
1	ARIEL M4 mission proposal	N/A	Jan. 2015
2	ARIEL Mission Requirements Document	ESA-ARIEL-EST-MIS-RS-001	1.3
3	ARIEL Science Requirements Document	ESA-ARIEL-EST-SCI-RS-001	1.3
4	ARIEL Payload Requirements Document	ARIEL-RAL-PL-RS-001	1.0
5	ARIEL Payload Definition Document	ESA-ARIEL-EST-PL-DD-001	1.0/ Mar. 2016
6	ARIEL Telescope Outline Requirements	ARIEL-RAL-RS-001	0.2 Oct. 2015
7	ARIEL Baseline Telescope Optical Prescription	ARIEL-RAL-PL-TN-001	3.1-02 Feb. 17

1.4 REFERENCE DOCUMENTS

RD #	REFERENCE DOCUMENT TITLE	DOCUMENT ID	ISSUE / DATE
1	MIRI Design Description Document	MIRI-DD-00001-AEU	
2	FM MIRI Imager Mirrors EIDP	MIRI-DP-00008-CSL	
3			

2 INTRODUCTION

The selection of the substrate for the mirror has to take into account many parameters. The first is the availability of the material in the proper form and size, since the ARIEL primary mirror is of about 1 m in diameter. Then the characteristics linked to the handling/manufacturing/polishing process and in particular to the required surface accuracy and surface roughness have to be accounted for. Use of an overcoat can be considered for materials that are difficult to polish bare.

The mirror has to be mounted and integrated in the telescope structure, so the coupling of the mirror substrate CTE with that of the mechanical structure has to be borne in mind.

For ARIEL, the impact of the temperature change between the ambient temperature at which the elements will be manufactured, aligned and tested to the operative temperature of 50-60K has to be considered. So the telescope mechanical design should have a high thermo-mechanical stability.

Other parameters are related to the requirements on the minimum throughput that impacts on the mirror reflectivity and thus on the choice of the coating. It is worth considering which coatings can be deposited on the material. The temperature range of use and storage should also be accounted for in matching, as well as, the CTE of the coating to the substrate. If an overcoat is present also that thermos-mechanical coupling has to be evaluated.

Because the diameter of the primary mirror is quite big (~ 1 m), the effects of the gravity changes and the impact of the lightweighting of the substrate has to be taken into consideration together with the allowable total mass of the telescope. Therefore the specific stiffness and specific strength of the material selected should be high in order to optimize this aspect of the design.

We can summarize the primary points discussed as follow:

- Substrate material and its capability to be polished/figured and way of measuring it
- Manufacturing and availability of the raw material in the proper form and size, and mechanical handling.
- Overcoat deposited to achieve better optical polishing.
- Reflective coating and CTE mismatch.
- CTE matching with mountings material and optical bench material.
- Thermal range stability, consistent CTE.
- High thermo-optical stability, which accounts for both thermal conductivity and CTE.
- Substrate lightweighting possible using conventional techniques.
- Material has high specific strength and high specific stiffness.

The materials that can be used for the ARIEL M1 mirror are rather limited. Those identified for this trade-off through brainstorming within the consortium and a review of the literature on other space telescopes of a similar scale are:

1. Aluminium or Aluminium alloy
2. Glass / ceramic such as Zerodur
3. Silicon Carbide (SiC) or C/SiC
4. Beryllium.

2.1 MATERIALS CONSIDERED

1 **Aluminium (RSA443) mirrors with Nickel Phosphor coating** with Aluminium support structures in matching CTE material. The principal drawback is the possible mismatch of the

coating CTE at low temperature. The feasibility of the use of this approach is questioned and would have to be demonstrated early in the program.

2. **Bare Aluminium mirrors (Al 6061 or similar)** with Aluminium support structures in matching CTE material. This alloy has the heritage of JWST MIRI though MIRI mirror is quite small (~ 200 mm x 200 mm).
3. **Zerodur mirrors**; with support structure in CFRP with a layup to attempt to match the CTE of the mirrors. There is heritage for the mirror, good finishing properties, but the design of the support system and matching CTE of the optics bench (OB) to Zerodur is potentially difficult. One possible solution for the OB should be CFRP panels, but CFRP design at cryogenic temperature is a development program for the industries involved in the consortium.

4 **Silicon Carbide mirrors**; with support structures also in SiC. It is feasible but polishing and handling of SiC is known to be difficult and require substantial process qualification.

5. **Beryllium mirrors**; with support structure either also in Beryllium or in a CFRP with a layup to attempt to match the CTE of Beryllium. This is a possible design option but there are health and safety implications of machining and polishing, there is no known capabilities to work pieces larger than about 600 mm in diameter. This rules out this option.

Glass materials have very good polishing properties, but are difficult to mount. Beryllium is very difficult to handle. SiC structures suffer from moisture release. An aluminium mirror mounted on an optical bench with the same material allows for automatic temperature compensation.

2.2 CRITERIA FOR ASSESSMENT

The following six criteria are used to assess each possible material against:

- Availability: How readily available is the raw material in the form which will be needed for the ARIEL primary mirror (at least 1.1 m diameter, 300 mm thick) blank? What would the procurement lead times and cost be to purchase the raw material? This is a qualitative assessment.
- Ability to Polish: What level of confidence and literature data is available to demonstrate that the consortium team and their subcontractors will be able to polish the material to meet the ~200 nm rms WFE specification on the telescope. This is a qualitative assessment?
- Thermo-Mechanical Design: What will be the complexity of designing the telescope system for manufacture at ambient and operation at cryogenic temperature? What level of confidence in the ability of coatings to survive the thermal environment, and what will be the complexity in design of the mounting scheme for the optics from the support structure? This is a qualitative assessment.
- Machinability for Light-Weighting: How easy it is design and then machine a light-weighted structure to the material? This is a qualitative assessment.
- Thermo-optical stability: this criterion depends on more than one parameter, i. e. thermal conductivity and CTE. A specific parameter called thermo-optical stability (thermal conductivity of the bulk material at 80K divided by its CTE at 50 K) is used as a quantitative assessment for this characteristic.
- Specific Stiffness / Strength: It is desirable that the telescope mirror and structure is as stiff as possible – it is expected that the first frequency requirements will likely drive the structural design of the telescope assembly. Similarly, a low density material is desirable in order to minimise mass. Therefore, specific stiffness (Young Modulus at Ambient temperature divided by density) is used as a quantitative assessment.

2.3 SCORING SCHEME

The scoring scheme against each of the criteria is show in Table 1 below.

Score	Qualitative Assessment	Range for thermo-optical stability (W/μm)	Range for Specific Stiffness (GPa m^3/kg)
0	**V. Bad**	<1	<0.01
1	**Bad**	1-5	0.01-0.02
2	**Difficult**	5-10	0.02-0.035
3	**Acceptable**	10-40	0.035-0.05
4	**Good**	40-100	0.05-0.1
5	**V. Good**	>100	>0.1

Table 1: Scoring Scheme for Trade-Off Assessment

The ranges in Table 1 have been defined as a quantitative assessment of each parameter based on heritage from previous projects and applications.

2.4 TRADE-OFF ASSESSMENT

The material properties assumed for each of the five possible materials are shown in Table 2 below.

Material	Conductivity @ 80K (W/K/m)	Stiffness - Young Mod (GPa)	Density (kg/m^3)	CTE @ 50K (μm/m/K)	CTE @ 293K (μm/m/K)	Specific Stiffness (GPa m^3/kg)	Thermo-optical stability (W/μm)
Al (RSA443)	135	100	2540	-NA	13.5	0.039	10.0 (*)
Al 6061	250	68.9	2700	2.9	23.6	0.029	86.2
Zerodur	0.7	90.3	2530	-0.5	0.001-0.1	0.036	-1.4
SiC	70	550	3210	<0.4	4.4	0.171	>175.0
Be	200	287	1850	<1	11.4	0.155	>200

(*) This value is for ambient T CTE

Table 2: Material Properties

The available CTE values of each considered material are drawn in Figure 1, the CTE values are plotted as a function of the temperature in the range from 22 K to ambient temperature. Unfortunately for the Al RSA443 only the value at room temperature has been found to be available. For the SiC the CTE is almost 0 under 150 K. For Zerodur, the CTE is very small and it is always negative under 0 °C.

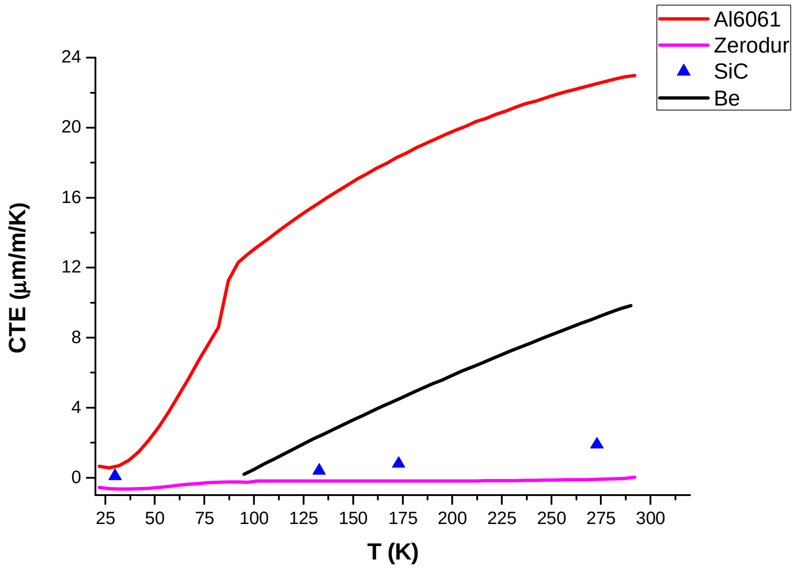

Figure 1 Instantaneous CTE vs T for the materials considered for the trade-off analysis.

Material	Availability	Ability to polish	Thermo-mechanical Design	Machinability for Light-weighting	Thermo-optical stability	Specific Stiffness (/strength)	Consortium ability to produce the mirror
Weight	5	5	4	3	5	4	5

Table 3: Criteria weighting scheme

The combined assessment of all of the materials against the criteria, including their weighting factors according to Table 3, is shown in Table 4.

The weights for the criteria in Table 3 have been defined after identification of the most important characteristics and priorities for the ARIEL telescope development and manufacturing process.

Material	Availability	Ability to polish	Thermo-mechanical Design	Machinability for Light-weighting	Thermo-optical stability	Specific Stiffness (/strength)	Consortium ability to produce the mirror	Score
Al (RSA443)	Difficult	Good	Bad	Good	Acceptable	Acceptable	Good	**93**
Al 6061	Good	Good	V. Good	V. Good	Good	Bad	Good	**119**
Zerodur	Good	V. Good	Difficult	Good	V. Bad	Acceptable	V. Good	**102**
SiC	Difficult	Difficult	Difficult	Bad	V. Good	V. Good	Good	**96**
Be	V. Bad	Bad	Good	Difficult	V. Good	V. Good	Bad	**77**

Table 4: Assessment of Materials Against Criteria

3 CONCLUSIONS

The consortium trade-off concluded that the highest levels of heritage and lowest risk for the consortium to build the telescope system was in option 2, Aluminium 6061 alloy. Although many of the other options are thought to be technically feasible they would require additional technical capability development or de-risking which is judged to be beyond the scope of the ARIEL Consortium in the Phase A study. Therefore Aluminium 6061 is selected as the baseline material for the consortium design activities in phase A, and for the use in the Pathfinder Telescope Mirror (PTM) program.