SIC CHALLENGING PARTS FOR GAIA

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ABSTRACT

GAIA is one of the cornerstone ESA missions which aims at compiling a catalogue of about one billion stars of our galaxy. Reaching the highly demanding scientific requirements lead ASTRIUM engineers to design a mechanically and thermally ultra-stable instrument. This is the reason why, thanks to its physical properties, the SiC turned out to be indispensable.
The **GAIA payload** includes the following hardware which is mainly **made of SiC** i) the 3 meters quasi octagonal torus structure, ii) two identical 1.5 meters TMA type telescopes, iii) the central sub-assembly which holds several folding mirrors and the “Radial Velocity Spectrometer”, iv) the focal plane and v) the “Basic Angle Monitoring”.
Due to the required large size (1 - 3 meters class), accuracy and shape complexity, developing and manufacturing these SiC parts was a real challenge for BOOSTEC. It is reviewed in this paper.

I. INTRODUCTION TO GAIA AND ITS BOOSTEC CONTRIBUTION

GAIA is the 6^{th} cornerstone of the ESA scientific program. It will provide positional, photometric and radial velocity measurements of about one billion star of our galaxy, with an unprecedented accuracy. The quite large payload has been designed by ASTRIUM [1][2]. It includes three science instruments:

i. **The Astro** which is devoted to the star angular position measurements (astrometry),
ii. **The Blue & Red Photometers which** provide continuous star spectra on 60 pixels in the band 330-1000 nm for astrophysics and Astro chromaticity calibration,
iii. **The Radial Velocity Spectrometer (RVS)** which provides high resolution spectra on 1260 pixels in the narrow band 847-874 nm and radial velocity measurements by Doppler effect.

Two 1.5 m TMAs point towards two directions forming a “Basic Angle” of 106.5°. The beams are then recombined with help of two folding mirrors, thus allowing them sharing a single large focal plane [3]. The astrometric accuracy (10-25 µarcsec at magnitude 15) relies on the very high stability of this “Basic Angle” (7 µarcsec over 6 hours). The SiC material appeared indispensable for obtaining the required **mechanically and thermally ultra-stable payload**. The mirrors, the main optical bench, the focal plane and also various subsystem structures are made of SiC.

BOOSTEC has been awarded from ASTRIUM a contract for assistance to the design and for manufacturing all this SiC hardware. All the flight models have been successfully delivered by the first half of the year 2010.

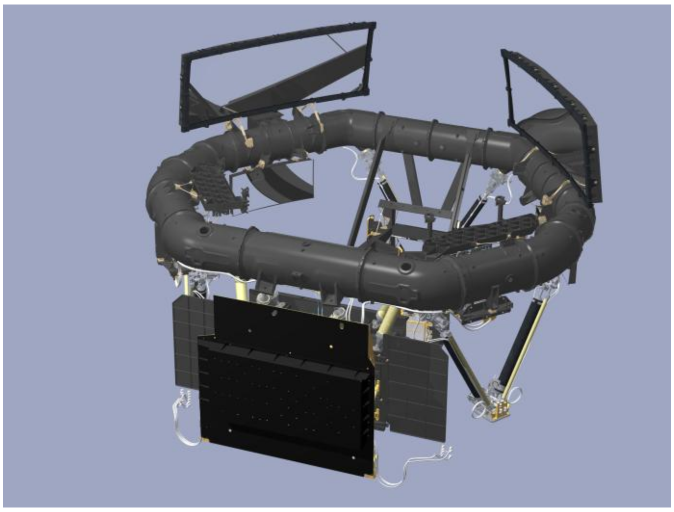

Fig. 1. The GAIA Payload Module features “all in SiC” architecture

II. BOOSTEC SILICON CARBIDE

BOOSTEC manufactures **sintered silicon carbide**. In comparison with the even most recently developed reaction bonded SiC including short chopped carbon fibers [4] [5], it features 24% higher thermal conductivity, 25% higher bending strength and 20% higher stiffness (even 13% higher specific stiffness). Its toughness is around 3.5 MPa.m$^{1/2}$ i.e. it is similar to the one of the C/SiC composites. Furthermore, the carbon fibers can bring some slight anisotropy and heterogeneity while the BOOSTEC SiC physical properties are perfectly isotropic and reproducible inside a same large part or from batch to batch.
The BOOSTEC SiC is easily polished as it is single phased. Thanks to its high purity, its coefficient of thermal expansion (CTE) fits quite perfectly well with the one of the extremely pure CVD SiC; this last one is obtained from chemical vapor deposition and it is commonly applied on the optical faces of SiC mirrors, in the aim to mask the few remaining porosities.
The sintered SiC of BOOSTEC shows no mechanical fatigue. It has been fully qualified for space applications at cryogenic temperature such as the NIRSpec instrument, which will be operated at 30K and embarked on the NASA James Webb Space Telescope [6].

Properties	**Typical Values @ 293 K**
Density	3.15 g/cm^3
Young's modulus	420 GPa
Bending strength / Weibull modulus (coaxial double ring bending test)	400 MPa / 11
Toughness (K_{1C})	3.5 MPa.m$^{1/2}$
Coefficient of Thermal Expansion (CTE)	2.2 . 10^{-6}/K
Thermal Conductivity	180 W.m/K

Table 1. Basic properties of BOOSTEC SiC

III. SiC TECHNOLOGY

A. Manufacturing monolithic parts

The process for manufacturing flight models of monolithic parts includes the following steps…

i. Isostatically pressing large blanks from fine SiC powder premix,
ii. Green machining (near net shaping) the pressed blank with help of high speed CNC milling machines,
iii. Sintering above 2000°C under protective atmosphere,
iv. Grinding and optionally lapping or polishing the optical faces or the interfaces,
v. Mechanical proof-testing,
vi. Final check and cleaning.

Commonly, BOOSTEC manufactures monolithic SiC parts of up to 1.5 m x 1.0 m x 0.5 m.
The parts are machined very close to the final shape at the green stage i.e. when the material is still very soft (similar to chalk). This is high speed machining and, furthermore, the collected dust is reused for producing new raw material. During the last ten years, BOOSTEC has continuously improved the reliability and also the speed of its process. New software for programming the CNC milling machines and also to verify the machining programs have been invested, thus allowing the green machining of very complex 3D shapes (see § V here after) with a high reliability. These are some of the reasons why BOOSTEC process is quite cost effective and quick.
After having SiC CVD coated the mirrors optical face, they are re-shaped by grinding in BOOSTEC thus recovering the previous < 0.05 mm shape defect; the large off-axis and also the flat GAIA mirrors have been successfully re-ground by this way.

B. Case of 3m class parts

The SiC parts the size of which exceeds 1.5m x 1.0m are obtained by **brazing** the assembly of previously sintered and ground pieces. The joint is made of a silicon alloy and it is generally less than 0.05 mm thick. This technique had been previously used for producing very large space parts such as the Φ 3.5 m Herschel primary mirror [7], the Φ 1.5 m Aladin-Aeolus primary mirror and the 1.8 m x 1.4 m NIRSpec optical bench [8]. The GAIA torus has been successfully brazed in 2009.

Fig. 2. One of the 19 GAIA torus segments *left*) during green machining, *right*) ready for brazing assembly

IV. ALL SiC TELESCOPES OPERATING IN SPACE

Now, mid of the year 2010, **six "all SiC telescopes"** based on BOOSTEC technology are **successfully operating in space**. Three of them are dedicated to earth observation from sun-synchronous orbit; the NAOMI Korsch type telescope of **ALSAT-2A** (operated by ASAL, Algeria) [9] and two Cassegrain type telescopes of Φ 600 mm aperture: the Remote Sensing Instrument of **ROCSAT-2** (operated by NSPO, Taiwan) [10] and **THEOS** (operated by GISTDA, Thailand).
GOCI is a TMA type telescope which is embarked on COMS, the Korean satellite operated by KARI [11]; it is also dedicated to earth observation but from a geostationary orbit, which is quite new.
The Narrow Angle Camera of **OSIRIS** is also a TMA; it is embarked on the ESA Rosetta satellite which is still flying towards the Comet 67 P/Churyumov- Gerasimenko. It has already made nice pictures of planets (Mars, the Earth, …) and also asteroids, taking profit from different flybys.
The ESA **HERSHEL** (Cassegrain type) telescope is undoubtedly the most challenging of them; it is the largest telescope in space [7]. Since June 2009, it has been successfully collecting the long wave-length radiation from some of the coldest and most distant objects in the Universe; it is clearly stated that its optical performances fully meet the scientists expectations.

V. GAIA PARTS MADE OF SiC

In total, the GAIA instrument will embark **284 SiC parts of 80 different types**; 106 of them are identical CCD supports. Further including the spare models, the GSEs, the mock-ups and the demonstrators, BOOSTEC has manufactured more than 1200 SiC pieces for the whole GAIA program (the witness samples and the ones dedicated to the powder batches qualification being excluded). A lot of these SiC parts were quite challenging, due to their large size and their highly complex shape. They are reviewed here after through a few examples.

A. The mirror blanks

GAIA includes two identical and large TMA type telescopes named ASTRO. Their three mirrors are aspheric and off-axis.

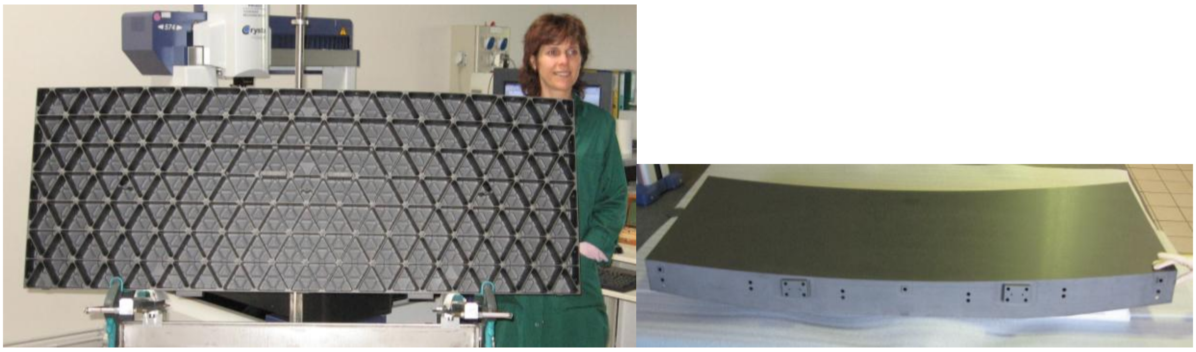

Fig. 3. Views of a lightweight M1 mirror blank, ready for CVD coating (38 kg)

The most challenging of them is the primary (M1) as it is the largest one: 1.50 m x 0.56 m. The process for manufacturing the blank (in BOOSTEC) and the one for polishing (in SAGEM-REOSC) have been validated through a scale one M1 demonstrator, ahead on the project. The thin ribs and particularly the huge number of back side cells can be noticed on Fig. 3.

B. The torus

The highly stiff and stable main bench of the GAIA instrument is hollow and quasi octagonal shaped, 3 m in diameter. It is made of 17 segments forming the large ring plus 2 additional brackets for M1 mirrors attachments; all of them have been joined by brazing, thus giving the required stiffness and stability. Individually, all torus segments were very challenging parts, due to their quite large size (0.5 - 1 m) and above all to the very complex shapes to be machined. Furthermore, they provide a lot of interfaces for setting-up on the satellite but also for mounting all optics and the focal plane as well. Before the assembly, they have been grinded and lapped very accurately. All individual torus segments have also been mechanically proof-tested.

The brazing assembly was undoubtedly the **key challenge** of the project. The 19 SiC parts had to be located accurately until the end of the brazing run (a single one!) which is performed around 1500°C. An ultrasound based technique has been developed specifically with the CEA (the French Nuclear Agency) for checking all the brazed joints. It allowed the detection and the cartography of possible voids down to a few mm². No significant defects were found in the brazed joints.

Fig. 4. Torus *Left)* Torus segment before brazing *Right)* Reception of the torus assembly in Astrium (< 200 kg)

C. The focal plane: CCD Supporting Structure and Cold Radiator (Fig. 5)

The 106 CCDs of GAIA are mounted on individual SiC substrates and then bolted on a large base-plate, the CCD supporting structure. Beside the main Astro CCD plane, it features 3 other planes which are tilted with different angles. This base-plate is then bolted on the Cold Radiator for stiffening and cooling purpose. All the useful areas of these both large SiC parts have been polished to a local flatness of 1 µm by the company WINLIGHT. The Cold Radiator is very large in its 3 dimensions (Fig. 5). It includes 6 accurately located interfaces areas which allow to hanging it under the torus, with help of thermally insulated bars.

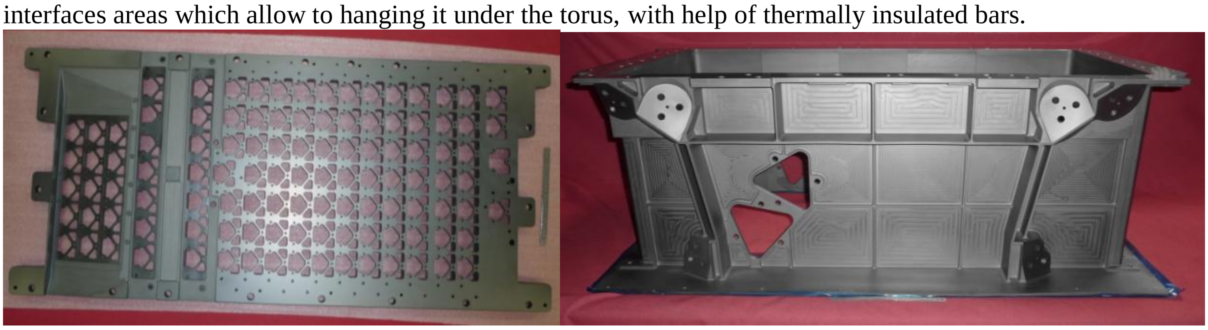

Fig. 5. Focal Plane

Left) The CCD supporting structure (1.15 m x 0.53 m - 11 kg)

Right) The Cold Radiator (1.17 m x 0.62 m x 0.41 m - 38 kg)

D. The Basic Angle Monitoring (BAM)

The extremely accurate "Basic Angle" is monitored with help of interferometry. For that purpose, the GAIA payload includes 2 optical benches. The main SiC part of them is a **very lightweight base-plate** (only 1 mm thick ribs) which **includes a lot of brackets** for mounting all the optics.

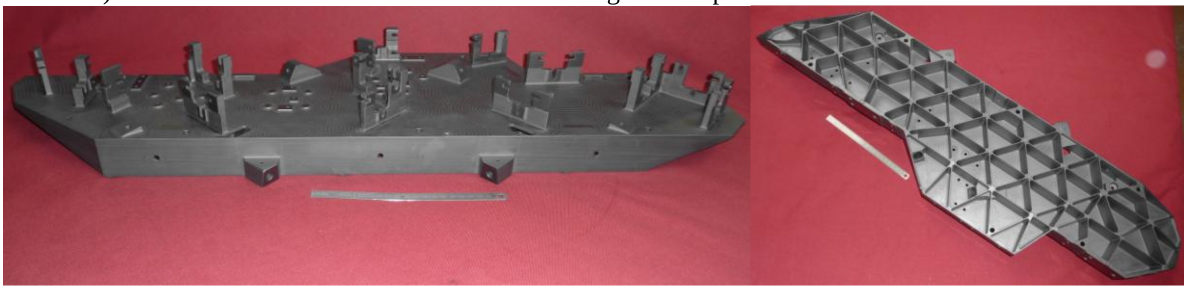

Fig. 6. Views of the BAM large base-plate (0.92 m x 0.28 m - only 5.6 kg)

VI. CONCLUSION

The BOOSTEC SiC has been selected for the GAIA payload which must be extremely stable, mechanically and thermally. After HERSCHEL, the GAIA very challenging project has confirmed BOOSTEC as the only company in the world capable of producing SiC space parts larger than 1 meter. These exciting activities go on with two large size TMA type telescopes still under way for the multispectral instrument of ESA SENTINEL 2.

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