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All-SiC telescope technology: recent progress and achievements

J Breysse[(1)]***; D Castel***[(1)]***; B Laviron***[(1)]***;D Logut***[(1)]***; M Bougoin*** [(2)]

(1)*EADS-ASTRIUM:31,rue des cosmonautes,31402 Toulouse cedex4, (France)*
E-mail: jacques.breysse@astrium.eads.net
E-mail: didier.castel@astrium.eads.net
E-mail: bernard.laviron@astrium.eads.net
E-mail: daniel.logut@astrium.eads.net
(2)*Boostec Industies:Zone industrielle F-65 460 Bazet,(France)*
E-mail: mbougoin@boostec.com

ABSTRACT

Last decade EADS-ASTRIUM and its partner Boostec, has become world leader in the field of Silicon Carbide (SiC) optical payloads. In the framework of earth and scientific observation, high and very high-resolution optical payloads have been developed. This leadership allowed EADS-ASTRIUM to propose a large and complete range of space-based system for optical observation. Ceramic mirrors and structures are becoming attractive for high precision light weighted opto-mechanical applications. Developments over the past 15 years by EADS-ASTRIUM and by Boostec have demonstrated the feasibility and versatility of the SiC material for numerous applications. The most favorable characteristics of this material are high stiffness, high thermal conductivity and low thermal expansion (CTE). Furthermore, SiC allows relatively quick and cheap manufacturing of components because the components can be shaped with conventional tools in a milling process of the green body material. Through different joining processes, SiC allows for large size applications and systems. Only the scale of the available production facilities, the largest of which currently is 4 m in diameter, limits size of the structures and mirrors that can be manufactured.

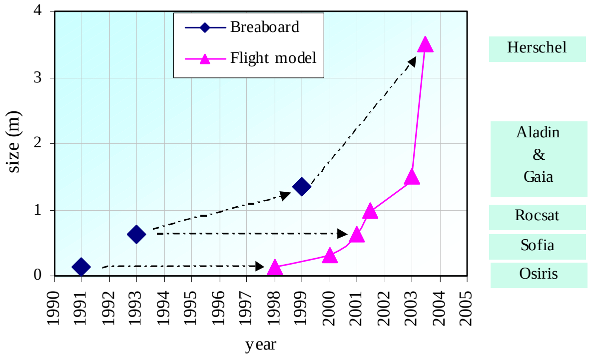
After a short recall of the SiC material properties, this paper describes recent impressive developments namely the ∅ 3,5m primary mirror for Herschel telescope, the ∅ 1,5m primary mirror for Aladin telescope and the 1,5m x 0,6 m mirror demonstrator for the GAIA mission. Main conclusion from the feasibility study of the∅ 3,5m SPICA telescope are also presented.

Keywords: Ceramic, Sintered Silicon Carbide (SiC), large optical payloads, lightweight mirror

1 INTRODUCTION

Over the past ten years EADS-ASTRIUM has developed the SiC technology for Space Applications in collaboration with a ceramic company BOOSTEC Industries (Tarbes, France). Its unique thermo-mechanical properties, associated with its polishing capability, make SiC an ideal material for building ultra-stable lightweight space based telescopes or mirrors. SiC is a cost effective alternative to Beryllium and the ultra-lightweight ULE/Zerodur technologies. In complement to the material manufacturing process, EADS-ASTRIUM has developed several assembly techniques (bolting, brazing, bonding) to manufacture large and complex SiC assemblies.

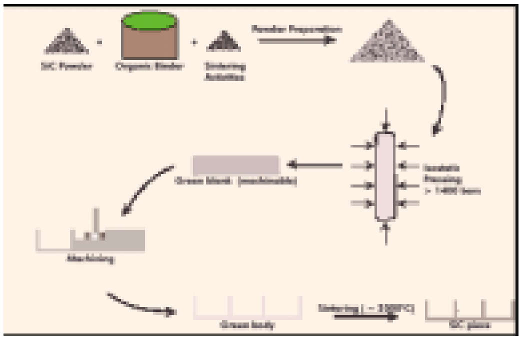
Recent EADS-ASTRIUM developments have shown the growth potential of the SiC technology. If originally SiC applications were limited to small size instruments and mirrors, last decade technological development, breadboarding activities and strong investment in large size manufacturing facilities had allow to reach the level of maturity required for the development of very large space instrument and mirrors. SiC manufacturing processes and manufacturing facilities, at Boostec premises, are now able to produce mirrors and structures up to 4 meters diameter, i.e. close to the limitation provided by the largest launcher fairings.



EADS-ASTRIUM SiC technology historic

__Sintered SiC: Manufacturing flowchart__

The major manufacturing steps of a sintered SiC blank is recalled in below figure



Manufacturing flowchart for Sintered SiC piece.

- SiC powder preparation: Silicon carbide fine powder is mixed with organic binders and a few added sintering elements.
- Green body manufacturing: The powder is isostatically pressed at a high pressure (> 1400 bars).
- Green body machining: The green body is machined to the desired shape. Reflectors light weighting is achieved on the green body.
- Sintering: The machined green body is pressureless sintered at about 2000 °C temperature.

Organic binders are removed during sintering process and the material is made up of 98.5% SiC. This explains its very homogeneous properties enabling both a good size control and an easy polishing. The sintering gives an isotropic shrinkage of SiC parts. The length contraction is about 17% but the uncertainty on the size of the sintered component is below 0.4%.

__Sintered SiC: Material basic properties__

The main features and advantages of SiC are as follows:

- Broad operating temperature range from 4 K (cryogenic) to 2000 K (high energy applications)
- Low specific density (< 3.2 g/cm³)
- High stiffness (420 GPa) and bending strength (>350 MPa)
- Low coefficient of thermal expansion: (CTE: 2.2 x 10^{-6} K-1 at room temperature and near zero below 100 K)
- High thermal conductivity (~ 180 W/mK)
- Isotropic characteristics of CTE, thermal conductivity, and mechanical properties
- Very high chemical, corrosion, and abrasion resistance
- No aging or creep deformation under stress
- No moisture sensitivity
- Fast and low-cost machining
- Short manufacturing times
- Ultra-lightweight capability (small wall thickness and complex stiffeners)

The material's most advantageous features for ground-based and space-based opto-mechanical mirrors and instruments are the combination of high stiffness, low CTE, and good thermal conductivity.

	Sintered SiC	Beryllium	Zerodur	Aluminum
Density (g/cm^3)	3.17	1.85	2.57	2.73
Young Modulus E/ρ (Gpa)	420	303	89	71
CTE α (ppm/K)	2.2	11,4	0,02	24
Thermal conductivity λ (W/m.K)	194	180	1,6	237
Specific heat cp (J/K/kg)	680	1880	810	900
Ratio E/ρ (specific stiffness)	133	164	34	26
Ratio λ/α (thermal distortion ratio)	88	16	80	10

Specific stiffness E/ρ *:* The higher is this value, the better is the material light-weighting capability for equal mechanical behaviour (e.g. equal first resonance frequency). However, a comparison only based on specific stiffness is rather theoretical, since it does not include manufacturing limitations such as the aspect ratio (rib thickness/ height). Actually, such limitations are not very constraining for SiC: an aspect ratio about 50 can easily be reached, and values as high as 80 with a rib thickness of 1 mm have been achieved.

Thermal distortion ratio λ/α: The higher is the better. It physically reflects that thermal distortions are not only proportional to the CTE, but also to the thermal gradients, which, under given thermal environment, drop down when the thermal conductivity (λ) increases.

A fundamental reason for the success obtained with Boostec silicon carbide material is that the material is extremely homogeneous, featuring very low in-built stresses and a single-phase crystalline microstructure. Performances reproducibility from batch to batch is a security for the development of space instruments.

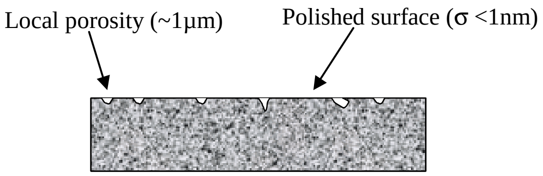
CTE homogeneity (4.5-300K)	< 1e-8 m/m/ °C
Fracture toughness (4.5-300K)	K_1C: ~3.5 MPa.m$^{1/2}$
Weibull modulus	> 10
Limit bending stress	4 points: ~ 450 MPa Bi-axial : >375 MPa

Good mechanical properties & excellent homogeneity make sintered SiC material suitable for high stable structures and mirrors.

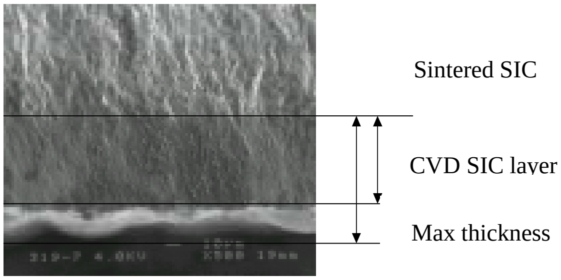
Sintered SiC: Optical Properties

BOOSTEC sintered Silicon Carbide is polishable (polishing convergence as good as for glass). The material can therefore be used for optics in the visible range. It can be metal-coated by using the same process than for silica glass and with similar performances. Several types of reflecting coating have been space qualified on the sintered SiC (Al, Ag, Au).

If pressureless sintering of SiC makes possible to reach a densification level over 98%,a consequence is that the raw sintered SiC exhibits a residual porosity of typically 2% in volume, therefore in surface. It can generate, for some applications (e.g. astronomic observation), too much stray light level . That the reason why, for these applications, we apply on top of the optical surface a mono crystalline SiC layer (CVD process) which thickness can vary from a few ten of µm to a few mm, depending on the final application. This high density SiC layer allows reaching roughness down to 0.1 nm.



Raw SiC



SiC with CVD cladding

SiC-cladding techniques and facilities*:* Two techniques have already been validated for cladding dense SiC on Sintered SiC. SNECMA process is chemical vapour infiltration (CVI), applied in mirror vertical configuration. SCHUNK process is chemical vapour deposition (CVD), nominally applied in mirror horizontal configuration, but also possible in vertical configuration. SNECMA experience is rather with 100 µm thickness. SCHUNK experience is up to a few mm coating thickness.. Available chamber dimensions, are in the range of ∅ 1,3m / 1.8m height

Sintered SiC: Joining Techniques

Available facilities allow manufacturing monolithic silicon carbide pieces for dimensions up to 1 m x 1.5 m which deals with the current limitation of the isostatic press. Nevertheless, this covers most of the needs for space applications. Consequently, manufacturing larger monolithic pieces would require significant industrial investments. Therefore, the cost effective and safe approach to manufacture large SiC pieces, such as HERSCHEL primary reflector, is to assemble together smaller pieces, which are well within available manufacturing capabilities. Furthermore joining techniques are absolutely necessary for telescope manufacturing where we have to integrate SiC mirror onto SiC mechanical structure, that the reasons why large R&T efforts have been spent to characterize and validate different assembly techniques. Through the several techniques that have been envisaged the following have been validated and are currently applied for flight space instruments.

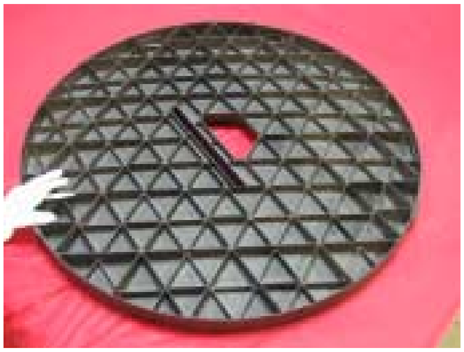
Bolting technique: Mechanical assembly of two pieces (SiC-SiC or SiC-metal junction) have been deeply characterized to allow a predictable behaviour of each assembly.

Herschel interface bipods are bolted onto SiC Mirror

Epoxy bonding: A set epoxy adhesives have been characterized over a wide temperature range, to determine achievable performances, such as strength and stability.

Rocsat RSI SiC tube is bonded on SiC base plate

Ceramic bonding: With this technique, the assembly of SiC pieces is performed in a "green body" status, by means of ceramic cement. Then they are bonded together during the sintering process providing a quasi-monolithic piece. Maximum dimensions of SiC pieces achievable with this process are mainly imposed by the sintering oven capacity. Current Boostec sintering oven capacity is about 1,7m x 1,2m.



This ∅ 1meter mirror demonstrator uses the Ceramic bonding technic (see [3])

High temperature brazing: The assembly of SiC pieces is performed while each SiC piece is already sintered Brazing technique consists to add a material between two sintered SiC pieces. EADS-ASTRIUM/Boostec technique is a high temperature brazing (~1400°C) that provides several great properties:

- Its CTE is matched to that of Silicon Carbide, say within 0.1 ppm/K or so.
- The brazing joint can be very thin. For very thin joints, the brazing strength is comparable or better than for SiC.
- The brazing is non-reactive, i.e. SiC is not attacked. Therefore, de-brazing is possible without any damage of the SiC parts.

The maximum dimensions of SiC pieces achievable with this process is imposed by the brazing oven capacity. Current Boostec brazing oven capacity is compatible uo to 4m diameter SiC pieces

SiC Brazing technic have been validated for the manufacturing of the ∅ 1.35 meter mirror demonstrator (FIRST breadboard: see [4];[5] &[6])

Sintered SiC: Boostec Manufacturing facilities

To achieve the development of the Herschel telescope, our partner, Boostec, has adapted the existing facilities and and has procure new ones providing an enlarge and validated SiC manufacturing line. From the SiC powder preparation up to the final grinding of a 4m-diameter SiC mirror, processes and facilities are now fully validated and verified to produce quasi-monolithic SiC piece as large as 4m-diameter.

	
SiC Powder preparation.: The synthesized SiC is milled in order to obtain the required fine grain size	Isostatic pressing: In the cold isostatic press, the raw material is very homogeneously compacted with help of a high-pressure liquid, through a rubber bag
	
Milling machine for Green blank machining: A near net shaping process makes very cost effective manufacturing	Sintering oven: under a non oxidizing atmosphere, the SiC sintering is performed at 2100°C
	
Grinding machine: when accurate geometry or size is required, areas of the sintered pieces are grinded	Brazing oven : performed at about 1400°C, allow the brazing of piece up to ∅ 4m

2 HERSCHEL PRIMARY MIRROR

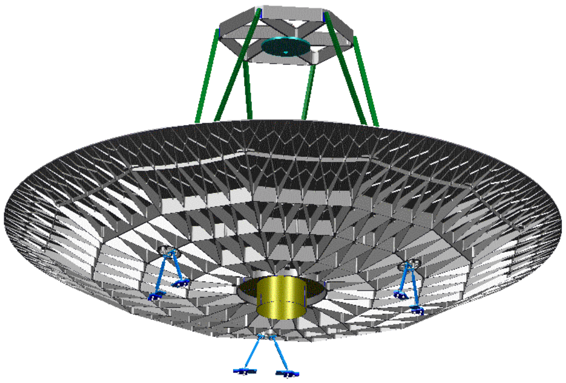
HERSCHEL satellite is part of HERSCHEL/PLANCK program of the European Space Agency (ESA) devoted to far infrared astronomy. Herschel main goal is to study how the first stars and galaxies were formed and evolved. The Herschel Space telescope, using silicon carbide technology will be the largest space imagery telescope ever launched. The Herschel telescope is to be delivered in 2005 for a launch planned for 2007. The telescope operates at cryogenic temperature (~ 80 K) in the far infrared wavelength range (80 µm to 600 µm) and it will be the largest telescope in orbit in 2007.

After a brief review of the telescope performances, we present the manufacturing status of the HERSCHEL primary mirror.

HERSCHEL telescope major requirements are recalled in the table below It consists of a large very fast parabolic reflector (diameter 3.5 m, f/0.5) and a hyperbolic secondary reflector connected to the primary reflector by the mean of a metering structure. The whole telescope is isostatically mounted on the cryostat structure, inside which the science instruments are located. The Herschel telescope will weight 300 kg rather than the 1.5 tons required with standard technology

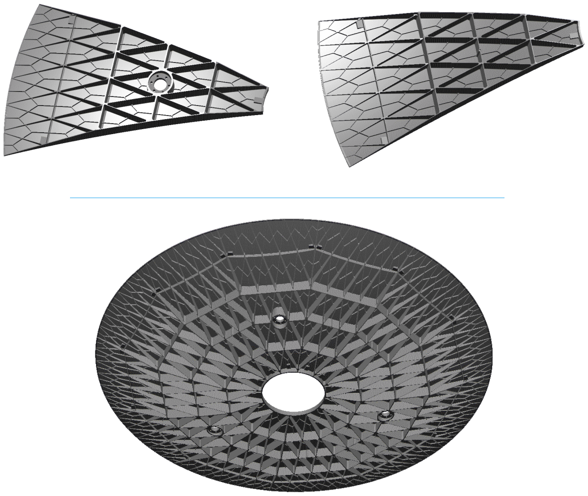
Parameters	
Primary reflector diameter	3.5 m (f/0.5)
Telescope focal length	28.5 m
Overall height	< 2.4 m
Overall mass	< 300 kg
Primary reflector mass	210 kg (~22 kg/m^2)
Operating wavelength	80 µm to 670 µm
Operating temperature	70 K - 90 K
Telescope Eigenfrequency	> 45 Hz lateral > 60 Hz axial
Primary reflector Eigenfrequency	> 50 Hz lateral > 100 Hz axial
Operating wavelength	80 µm to 670 µm
WaveFront Error (WFE)	< 6 µm rms

A 1.35-meter demonstration model, completed by 1999, and the manufacturing a full-scale petal of the 3.5 m reflector in 2001 has secured the development of the flight model. (see[5])



Herschel Telescope view

The most complex element is obviously the ∅ 3.5 m primary reflector that is composed of 12 SiC segments brazed together .The basic idea is to manufacture the primary reflector in twelve segments brazed together at high temperature: the manufacturing of each individual segment is well within available facilities capabilities and can be efficiently achieved with low development risk. For obvious interchangeability reasons, the segment designs are forced to nearly identical. As a result, the reflector is made of only two types of segments: three identical segments offer interfaces for the bipod isostatic mounts for the fixation of the whole telescope on the cryostat as well as for the fixation of the structure holding the secondary reflector, while the nine other segments are identical one to each other. The segment is open-back light weighted with triangular cells. The rib heights and thickness are optimised for minimizing mass while meeting frequency requirement. As an illustrative example, the rib height varies from 0,1 mm in the centre of the segment to a few mm at the edge. The thickness of the optical surface is lower than 3 mm.

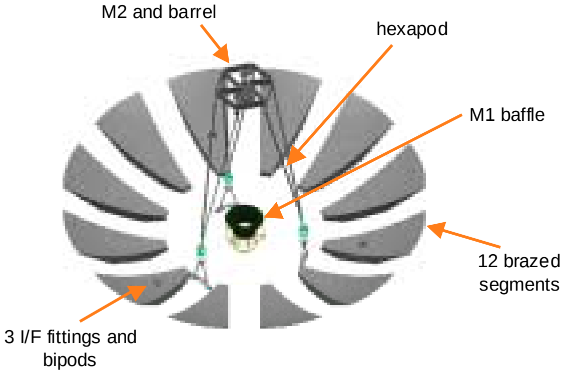


HERSCHEL Primary Reflector design: segments with or without I/F

When all segments are sintered and their edges are ground (edges planarity better then < 30µm over 1,5m), each segment is accurately and iso-statically positioned with respect to the adjacent ones on a support tool. The aim is to guarantee the geometrical adjustments for the brazing process, and to define the relative positions, which minimize the final mass of the reflector, while keeping a final skin thickness higher than 2mm. Affectation of each segment on the supporting tool is done according the results of each individual segment geometrical measurement. The positioning error of each segment with respect to theoretical optical surface is less than 100µm, gap between two adjacent segment remains below a few µm. Each segment is then fastened to each other by dedicated tools, which are compatible with the 1400°C temperature environment of the brazing oven. Then the so made segments assembly is move inside the brazing oven, to undergo the brazing sequence. The flight model brazing has been successfully performed. Ultrasonic inspection, performed after the brazing sequence, has shown that all segment were perfectly brazed to each other. Longitudinal shift of segment front faces, after brazing, remains within a 100µm tolerance

The next manufacturing step of the mirror is the grinding operation of the optical surface (presently on going). During this grinding operation, the reflector is maintained by the 3 bipods and by several supporting points that reduce potential distortions under the grinding efforts. The bipods fixture must guarantee the perfect positioning of the mirror on the grinding machine, in order to get the optical axis and the mechanical axis identical. A fine translation adjustment of the mirror allows to reduce the reflector thickness differences, so minimizing the mass of the reflector once grounded. As an order of magnitude, 1mm uniform thickness of the optical surface represents 30kg in mass. As the mass is decreasing during the grinding, the height of these supporting points is calibrated to take into account the surface release. After grinding the surface error is expected to be about 100 µm with respect to the best-fit parabola. The parabola radius of curvature is practically determined at this step and will experience small changes only after polishing. Then, the mirror will undergo the polishing operation at Opteon premises in Turku (Finland) to lower the wave front error down to 3 µm rms, while the surface roughness will be below 30 nm. The reflector will be aluminium coated at Calar Alto Observatory facility with a thickness larger than 200 nm for ensuring a low emissivity (and a high reflectivity) at Herschel wavelengths.

About 30 full size segments have been manufactured for the development for the two models of the primary mirror as well as for the different validation mock-ups



Exploded view of Herschel telescope

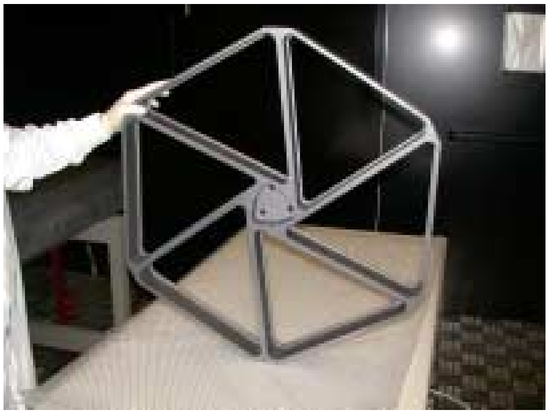
Development status: The flight primary reflector, successfully brazed in November 2003, is presently under grinding to reach the final parabolic shape. Reflector is planned to be ready for assembling on the telescope end of this year 2004.

Each segments is accurately positioned on a tool

Mirror assembly prior brazing phase

Mirror after brazing phase

Control after the brazing oven and bipods integration



Secondary mirror barrel

3 ALADIN TELESCOPE PRIMARY MIRROR

The ALADIN instrument (Aeolus mission), is a Doppler Wind Lidar based on a diode-pumped Nd-YAG laser and a direct detection receiver. The instrument is pointing at 35° across-track from the nadir in the measurement mode. The Cassegrain telescope is an a-focal telescope made of two parabolas. The input pupil diameter is 1.5 m and the output pupil diameter is 36 mm.

Aeolus spacecraft: Artist view

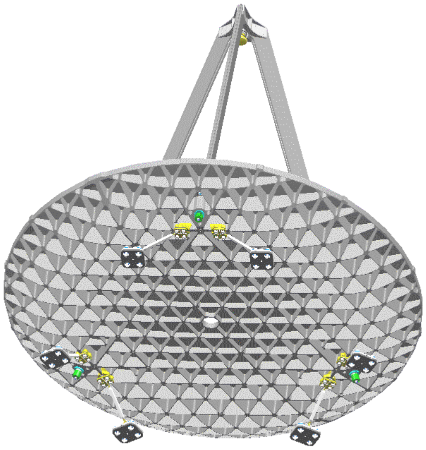
The ALADIN Telescope functions are:

To transmit the laser beam along the requested line of sight referenced with respect to the star tracker reference frame

To collect the laser beam flux partially reflected by the atmosphere to delivered it to the optical bench.

The whole SiC telescope concept makes use of the Herschel Telescope one. It consists in a ∅1.5m parabolic primary reflector made of two half SiC circular segments brazed together diametrically. The secondary SiC mirror (∅46: convex parabola: RoC=65mm) is fixed by means a SiC tripod structure on the primary mirror (M1-M2 distance=1320mm). Each of the 3 struts of the tripod is constituted by two half SiC shells bonded together to achieve the required stiffness while minimizing the occultation ratio to keep it below 6.5% for emission, assuming a Gaussian flux distribution. The 3 legs are glue together, on topside, by means of SiC fittings. Fixation onto the primary mirror is achieved through 3 titanium end fittings glued on the bottom side of each leg; then are bolted on M1 reflector through M10 titanium bolts. The thin part of the end fittings aims to provide a quasi iso-static fixation by releasing of radial and tangential degrees of freedom.

The whole SiC telescope assembly is fixed onto the CFRP instrument carrying structure via 3 bipods, which also provides an iso-static interface.

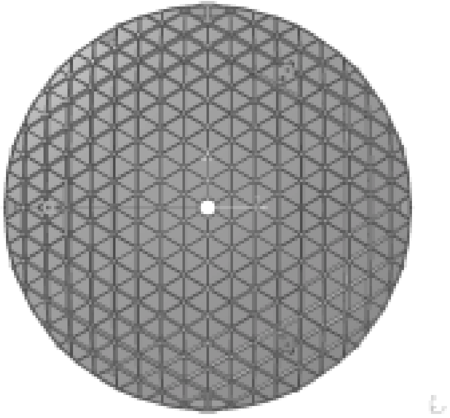


Aladin telescope overview

Sintered Silicon Carbide (SiC) material has been chosen as baseline material for the telescope as it offers the best compromise regarding mass and stiffness performances.

The primary mirror is an open back structure. The thickness of front face skin is 3 mm. The main rib network is organized in isosceles triangular cells to ensure the mirror required stiffness.

The front face figure is a parabolic shape with a curvature radius of 2700 mm ± 2.7 mm. The mirror sag is about 100 mm while the total mirror envelope thickness is 125 mm (rear face to front face edges). It will be polished on bare SiC



Rear face of the ∅1,5m primary mirror

As for Rocsat instrument, the focus quality can thermally be adjusted by means of controlled heaters, preventing the use of a refocusing mechanism.

Parameters	
Primary mirror dimension	∅ 1.5m focal
Primary mirror focal length	1,35m (f/0,9)
Telescope total mass	< 80 Kg (current status 72 Kg)
Primary mirror mass	50 kg (28 kg/m²)
Operating temperature	18°C-25°C
Telescope Eigenfrequency	>100 Hz (if Meff >10% total mass) >50Hz (if Meff <10% total mass)
Primary mirror Eigenfrequency	> 150 Hz
Operating wavelength	360 nm
Telescope Wave Front Error (WFE)	See below performances
Primary mirror Wave Front Error (WFE)	< 150 nm rms
Micro roughness	≤ 2 nm

Aladin telescope main requirements

Criteria		Telescope results	Requirement
Mid Term Weekly period	WFE	13 nm	17 nm
	Defocus	2 µm	± 2 µm
	Δ LoS	0.7 µrad	9 µrad
Long Term	WFE	290 nm	340 nm
	Defocus	20 µm	± 24 µm
	Δ LoS	45 µrad	130 µrad

Aladin telescope WFE and stability performances

Half mirror "green body" before sintering phase

Aladin primary mirror after brazing

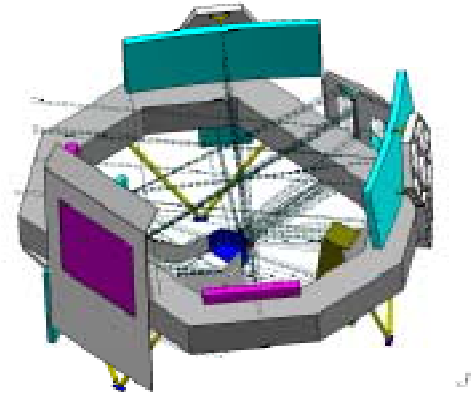
Development status: Presently almost all SiC pieces of the telescope have already been manufactured. The two models of the primary mirror (OSTM and FM) have been successfully brazed. Presently, the optical surface will be grinded by Boostec, prior the polishing phase to be perform by Opteon (Finland). Flight model reflector is planned to be ready for assembling on the telescope early 2005, while OSTM model (not polished, but equipped with mirrors sub pupil) will be ready for assembly in the forthcoming months.

4 GAIA TELESCOPE MAIN MIRROR

GAIA is proposed as a follow-up of the highly successful HIPPARCOS mission. GAIA will provide the position, annual proper motion and parallax of about 1 billion objects, with an accuracy better than 10 micro-arcsec for stars with magnitude lower than $m_V = 15$.

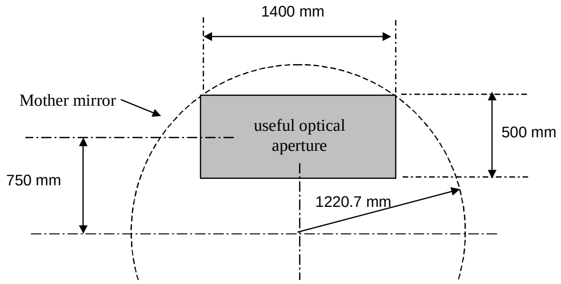
EADS-Astrium has been selected by ESA to manufacture and test a full size demonstrator of the primary mirror of the GAIA telescope. It will be coated with CVD SiC, then polished with an off-axis aspheric figure and coated with protected silver.

The main GAIA instrument, named ASTRO, is made up of two telescopes with their lines of sight separated by an angle of 106 degrees called the Basic Angle. The satellite is spinning so that these telescopes cover great circles of the celestial sphere



GAIA Instrument overview

The two telescopes are of three-mirror-anastigmat type (TMA). The primary mirror which polishing is discussed in the present document is an off-axis aspheric (close to a paraboloïd) mirror with a rectangular shape of 1.44m x 0.54 m that defines the input pupil area of the ASTRO telescope. The mirror substrate is made of sintered silicon carbide (SiC) as well as the entire instrument structure to take advantage of the optical, mechanical and thermal characteristics of this material. The material homogeneity ensures a perfect dimensional stability to the instrument as required by the final needed accuracy.



Off-axis mirror with offset distance 750 mm from “mother mirror” revolution axis.

If the technology for manufacturing large SiC mirrors has been proven by the HERSCHEL development, the main purpose of the proposed GAIA mirror demonstrator is to prove that the polishing of such aspheric large mirror is achievable, fulfilling the GAIA performance requirements (wavefront error of $\lambda/30$ over the whole surface in the visible band) at ~160K.

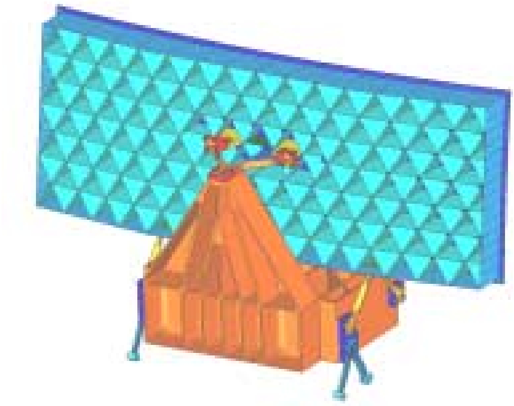
The monolithic GAIA mirror demonstrator is a flight representative model, which will be fully tested at the working temperature (160K). For that purpose, the mirror is fixed to a SiC support structure via 3 isostatic devices.

Parameters	
Primary mirror dimensions	1.44m x 0,54m
Telescope focal length	~47 m
Primary mirror mass	36 kg
Operating temperature	~160 K
Demonstrator Eigenfrequency	> 70 Hz lateral > 100 Hz axial
Primary mirror Eigenfrequency	250 Hz is achieved on ideal isosatic mounting
Operating wavelength	Visible
Telescope Wave Front Error (WFE)	< 45 nm rms
Primary mirror Wave Front Error (WFE)	< 20 nm rms with minimization of non-symmetrical optical defects
Micro roughness	≤ 1 nm

The main performances applicable to the GAIA primary mirror are summarized in above table

The proposed primary mirror is an open back structure with 2 kinds of ribs. A clever ribs design ensures quilting effects below 6nm and a stiffness minimize lateral gravity effect below 20 nm.. The main ibs are organized in isosceles triangular (7 cells in the height of the mirror, 15 cells in its width). sub-stiffeners divide each of the main triangular cells in 4 identical sub-triangles. The thickness of front face skin is less that 3 mm

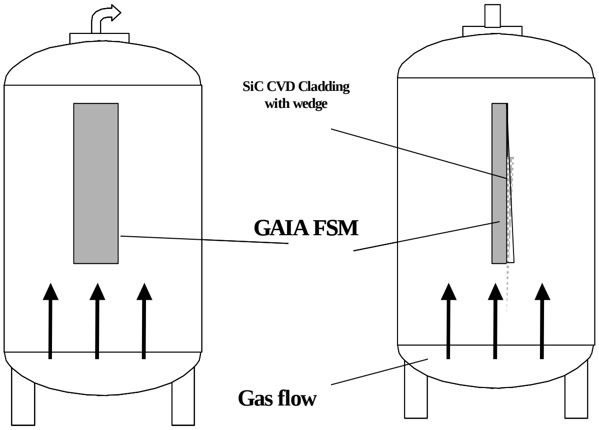
The front face figure is close to a parabolic shape with a curvature radius of 5575 mm +/- 5 mm. The mirror sag is about 50 mm while the total mirror envelope thickness is 150 mm (rear face to front face corners).



Demonstrator Overview

The achievement of fine polished surface involves a dense SiC coating to be deposited, at a thickness of at least 200 µm, to compensate mainly for sintered SiC grinding accuracy, CVD SiC cladding thickness uniformity and optical lapping properties. SCHUNK facilities and experience has been selected for the application up to few mm dense SiC cladding.

In parallel to the detailed design of the mirror, validation and characterisation of the uniformity of the layer has been obtained by coating a mirror representative sample in the CVD chamber.



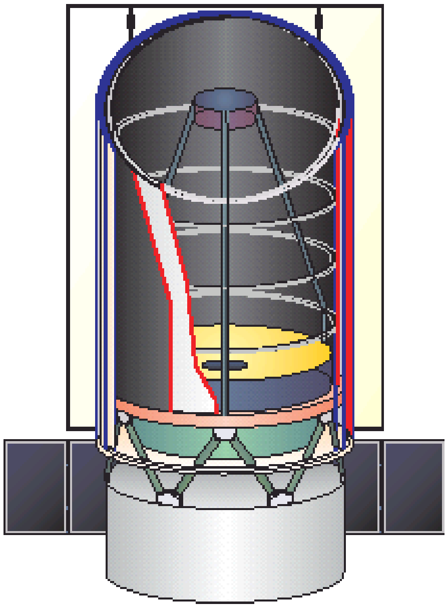
The position of the mirror along the gas flow imposes a specific validation to obtain an uniform CVD layer thickness.

SAGEM has been selected for the polishing of the GAIA primary mirror which is a complex operation due to the required high optical quality (λ/30) combined with its large size, its large offset from symmetry axis and due to the large departure from the best sphere. (~280 µm).

Development status: The detailed definition of the mirror is now completed. Presently the manufacturing of the SiC blank is on going at Boostec premises. Shunk will performed CVD cladding on summer 2004, Sagem will complete the polishing phase and the silver coating up early 2005. The mirror will then undergo a vibration and thermal tests campaign. Reflector is planned to be ready for final review planned in may 2005

5 SPICA PRIMARY MIRROR

In 2003, EADS-Astrium has been selected by Sumitomo (Japan) to perform a feasibility study, funded by JAXA/ISAS, of the SPICA telescope.



Artist view of the Spica spacecraft

The SPICA telescope (to be launched in 2010) is cooled down to 4.5K to be suitable for mid to far infrared observations. To overcome mass problems and life limitation given by classical liquid helium cooling system, a warm launch, cooled telescope design concept (i.e. the telescope and focal plane are only cooled while in orbit) has been selected by JAXA to achieve high sensitivity throughout the infrared wave band. This concept reduces significantly the total size and enables the payload fairing of the H-IIA rocket to accommodate a telescope with a non-deployable 3.5m primary mirror. Radiative cooling of the telescope, down to 15K, is passively achieved through a set of shields. The Focal Plane Instruments (FPI) and the primary mirror, attached on the instrument bay, are both cooled with a 4.5K mechanical cooler. Cooling of the Ge:Ga detectors installed within the FPI, is performed by a 1.7K mechanical cooler. Hence, a conventional “monolithic mirror” design makes the mission technically feasible and reliable.

The core wavelength range of SPICA is 5-200µm which will be covered with a Mid-infrared Camera & Spectrometer instrument and a Far-infrared Camera & Spectrometer instrument. Option for near infrared (1-5 µm) and sub millimetre-observing capability are also under study but not yet base-lined for SPICA. The main mission specification, applicable to the SPICA telescope, is synthesized in below table. The second Sun Earth Lagrangian liberation point L2 has been chosen as an orbit for the SPICA observatory-type infrared mission.

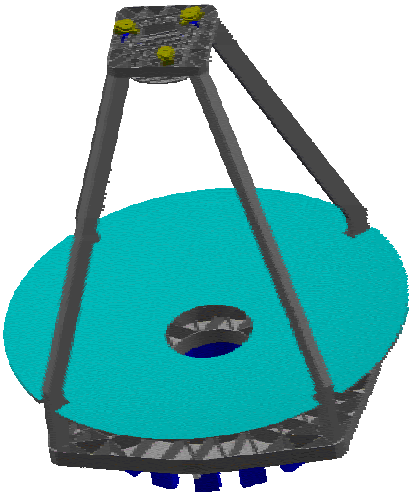
The SPICA optical system, defined by Sumitomo/Nikon is a Ritchey Chretien design for its quite large Field Of View. The primary mirror figure is close to a parabola and the secondary is an hyperbola. The F number of the primary has been limited to reduce its manufacturing difficulty but also to have a lower secondary magnification and thus a lower sensitivity to relative primary vs. secondary displacements. The mirror remains however quite fast to keep a reasonable overall telescope length. To minimise diffraction effects, a four struts structure concept has been choosen to support the secondary mirror and its refocusing mechanism. This structure is fixed at the primary mirror periphery, onto the optical bench, to limit the occultation ratio.

Parameters	
Primary mirror dimension	∅ 3.5m (~f/1) *(Herschel f/0,5)*
Secondary mirror dimension	∅ 0,8 m *(Herschel= ∅ 0,3 m)*
M1-M2 distance	~3m *(Herschel= 1,6m)*
Telescope effective focal length	~20m
Telescope total mass	< 500 Kg (without focal plane instrumentent optical bench)
Primary mirror mass	< 300 kg (~30 kg/m^2)
Operating temperature	4.5K (300K during launch)
Telecope Eigenfrequency	> 30 Hz lateral direction > 60Hz longitudinal direction
Operating wavelength	5-200 µm (diffraction limit @ 5µm) 1- 800µm (optional)
Telecope Field of View (FoV)	20 arcmin ∅
Telescope Strehl ratio > 0.8 @4.5K for:	Equivalent Wave Front Error (WFE)
λ= 5µm / 9 arcmin ∅FoV	0,376 µm
λ= 20µm /18 arcmin ∅FoV	1,5µm
λ= 200µm /20 arcmin ∅FoV	15 µm
λ= 5µm 18 arcmin ∅FoV	0,376 µm
Micro roughness	≤ 25 nm rms

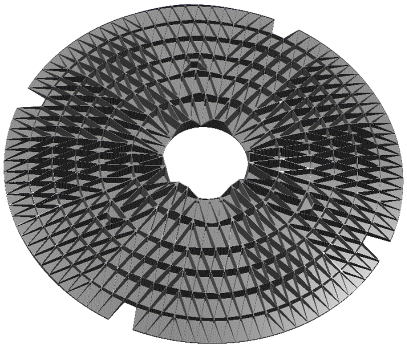
SPICA telescope main performances

Compared to the Herschel telescope, SPICA telescope WFE performances are about 20 times more challenging, while keeping mass budget in a reasonable target. The phase A study, which was mainly focussed on the primary mirror definition and on the telescope verification aspects has allowed to conclude that the sintered SiC technology is perfectly suitable to achieve the above SPICA telescope performances.

As for Herschel, primary mirror proposed design is made of twelve brazed segments (mass (< 300 kg)



Overview of the SPICA all SiC telescope



Overview of the∅ 3,5 m SPICA primary mirror

Development status: Feasibility study has been completed on January 2004. Next design phase is planned on mid 2004.

6 CONCLUSION

After more than ten years of development and characterisation, Sintered Silicon Carbide manufactured by BOOSTEC, has now reached the level of maturity required for the development of large space mirrors and structures. The well-defined and cost efficient SiC technology, that still presents a high growth potential, have been successfully used for the Osiris and Rocsat instrument. The development of Herschel telescope has represented a turning point for the SiC technology by the significant industrial and technical step it has allowed. Manufacturing of large mirrors and structure, such those of Herschel, Aladin and GAIA, can be viewed as the first representatives of the new generation of large spaceborne telescopes for science or earth observation.

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