International Conference on Space Optics—ICSO 1997

Toulouse, France

2–4 December 1997

Edited by George Otrio

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International Conference on Space Optics — ICSO 1997, edited by Georges Otrio, Proc. of SPIE Vol. 10570, 1057028 · © 1997 ESA and CNES · CCC code: 0277-786X/18/$18 · doi: 10.1117/12.2326634

POLISHING PROCESS OF SINTERED SIC MIRRORS

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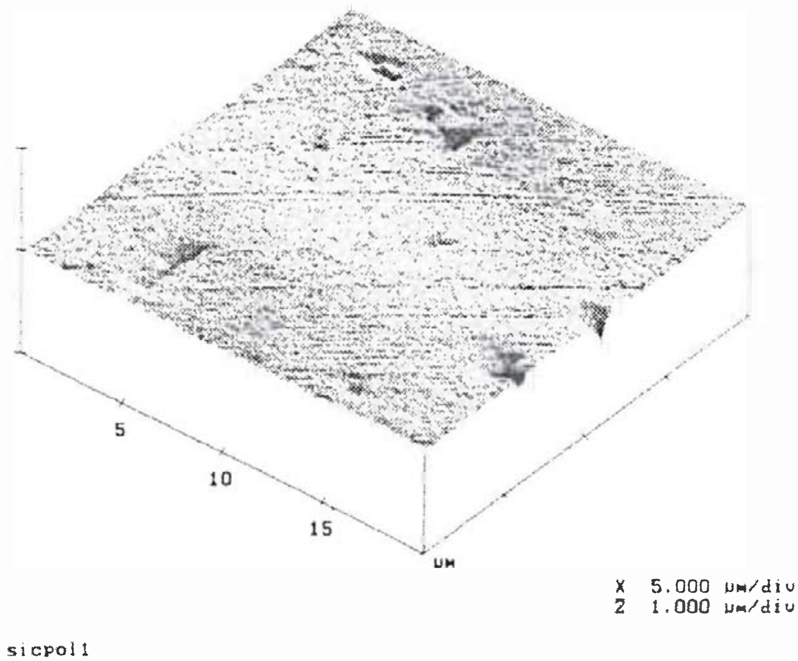
RÉSUMÉ - Les projets d'instruments optiques actuellement en phase de définition par MMS s'appuient sur l'utilisation de miroirs en SiC fritté. La porosité intrinsèque du matériau nécessite néammoins dans la plupart des applications d'envisager le dépôt d'un revêtement compact et exempt de défaut permettant d'atteindre des niveaux de diffusion comparables à ceux obtenus avec le verre. Ce dépôt doit être polissable par les techniques utilisées pour le polissage des verres. Cet article présente les résultats obtenus par MMS pour différents dépôts envisagés dans le but d'abaisser le niveau de diffusion. Les tests de performance optique ont été effectués sur des miroirs représentatifs d'une séquence complète de traitement et de polissage et couvrent le niveau de diffusion, la qualité de surface obtenue et la sensibilité thermoélastique de l'ensemble, dans un objectif d'industrialisation pour des projets spatiaux à court terme.

ABSTRACT - *Advanced optical systems, currently under consideration at MMS propose the use of sintered SiC. Due to intrinsic porosity of sintered SiC, it is required for several applications to deposit on the optical surface a layer of a material free of porosity and of defect. This coating aims at reaching scattering levels achieved with the use of glass materials. Polishing of this layer shall be compatible with glass polishing techniques. This article describes the optical performance reached by MMS with the use of different coatings in the scope of reducing the scattering level. The optical performance tests were done on space borne representative mirrors upon completion of polishing of the optical surface. The tests were on scattering performance, on wavefront error performance and on thermoelastic sensitivity. The process was developed in view of industrial application to spatial projects in short term.*


5
10
15
µm
X 5.000 µm/div
Z 1.000 µm/div
sicpol1

1 - SINTERED SIC OPTICAL PERFORMANCE

Intrinsic porosity of sintered SiC is linked to the process of fabrication. Porosity is around 3 % in volume. Holes due to intrinsic porosity can be observed at optical surface (Fig. 1). These defects increase the surface microroughness and then the scattering level in proportion.

Fig. 1: observation of the optical surface microroughness on atomic force microscope

The figure here after (Fig. 2) represents the Bi-directional Reflectance Distributing Function - BRDF - of a well polished surface of a sintered SiC sample: the recorded scattering level is equivalent to the one of a glass surface of 15 nm RMS microroughness. Observation on atomic force microscope put in evidence that the optical surface was polished to a level of 1 nm RMS of microroughness. Hence it is demonstrated that the recorded scattering level comes from the holes. - The equivalent microroughness of the surface, deduced from the recorded scattering level, derives from the following well known equation: Total Integrated Scatter = $(4.\pi.\sigma / \lambda)^2$, where σ is the surface RMS microroughness.

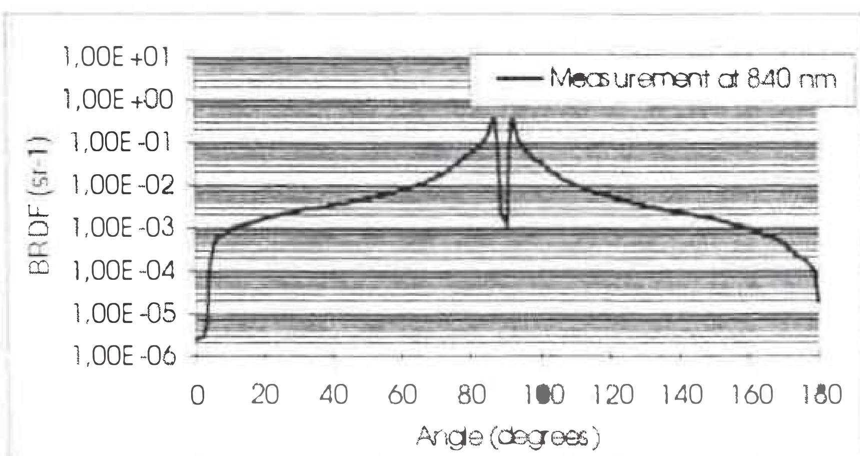


Fig. 2: BRDF measurement of a well polished sintered SiC sample aluminium coated, illuminated at normal incidence - *(With courtesy of CNES)*

2 - OPTICAL PERFORMANCE REACHED WITH A COATING ON SIC SUBSTRATE

2.1 - Definition of the coatings necessary geometry as a function of the polishing sequence

In order to improve the scattering performance down to 1 nm RMS of microroughness. any technique to make the sintered SiC compact must be given up. Indeed the improvement should lead to a porosity below 0.02 % which can be considered very unlikely to achieve with regard to the state-of-the-art in this domain. So the effort was put on coatings to be deposited on SiC substrate which would be compact and free of defects. Polishing of the coatings has to be compatible with glass polishing techniques. The thickness of the coating to be deposited shall be thick enough to fill the holes. A provision is also to be taken with regard to the material necessarily removed during polishing. It can be considered that the material removed during polishing is of three origins:

1 - Material removed to reach the right surface shape. The removed amount depends on the surface shape of the substrate before coating deposition: the closer to the right shape is the surface before coating deposition, the less material will have to be removed.

2 - Material removed to reach a low microroughness. This final step of polishing is made with very small abrasive particles and is known to be a very minor pie of the material removed.

3 - The coating thickness can be non uniform over the surface due to conditions of growth of the layer on the substrate. So the spots on the layer shall be removed before starting the polishing of the shape. Useful thickness is then equal to the minimum thickness of the layer over the coated surface.

Sequence of polishing is of major importance for the determination of the minimum necessary thickness of coating layer: a pre-polishing of the surface to be coated - corresponding to step 1 of polishing - minimises the necessary minimum thickness of coating to be deposited. But this implies the process to include two sequences of polishing: before and after coating deposition. This approach leads to a complex industrial organisation. This puts very large constraints on cost, on schedule and on risk of development. On the opposite way is the process retained by MMS which aims at securing future industrial developments: the surface to be coated is only fine ground (Fig. 3). Then polishing is postponed after coating deposition and is achieved in one step. The minimum thickness of coating to be deposited includes steps 1, 2 and 3 of polishing plus a provision for securing the polishing sequence without putting constraints onto the polishing operations.

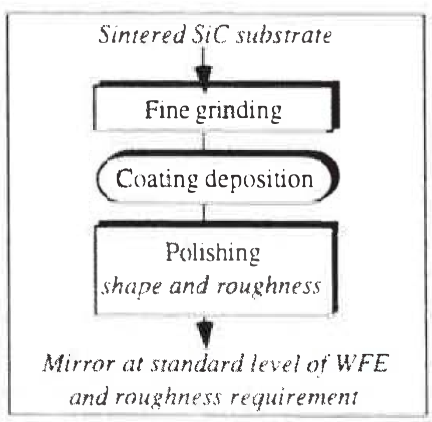


Fig. 3: process retained by MMS which aims at securing future industrial developments

2.2 - Selection of the candidates coatings and definition of the coatings depositions success criteria

2.2.1 - Presentation of the candidates coatings

The different candidate coatings selected for their good compatibility with sintered SiC and for their capacity to be polished were *SiC Physical Vapour Deposition, Si Plasma Deposition, SiO2 Physical Vapour Deposition, SiC Chemical Vapour Deposition*. Si and SiO2 material would present many disadvantages linked to their association with a different substrate material. Ones of the majors concerns anticipated were: high bi-metallic effect due to the difference of CTE, risk of adherence ageing after thermal cycles, difficulties to characterise the wavefront error during polishing because Si layer is transparent. So it was decided to keep Si plasma deposition and SiO2 physical vapour deposition as backup of the techniques of SiC deposition - SiC-CVD and SiC-PVD - to be investigated first.

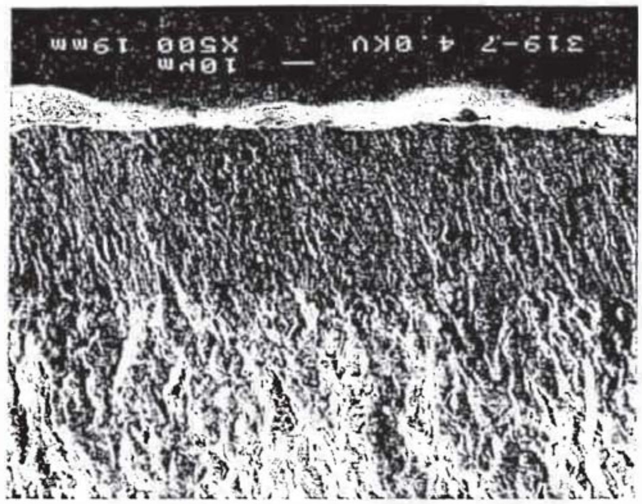
The coatings were deposited on samples representative of space borne mirrors. The samples consist of circular pieces of 100 mm diameter, light-weighted on their back.

2.2.2 - Definition of the coatings depositions success criteria

The success criteria of coatings depositions are two-fold : performance criteria and qualification criteria:

1 - Performance is linked to polishability which can be defined as the capacity of achieving the required surface shape and the required scattering level. But also thermoelastic deformation over an operational thermal range is one of the performance success criteria: the difference of process between sintered SiC and SiC vapour deposited can lead to weak difference of CTE.

2 - Space qualification is not a major concern as far as SiC material is already used in flight. However, adherence between sintered SiC and SiC vapour deposited has been verified following an ESA standard peeling test. - It is obvious that abrasion during polishing is by far the hardest adherence test. - Thermal cycles and humidity cycles generally used to simulate ageing are not of concern because coating is deposited at very high temperature in a chamber filled of vapour: any cycling would be far less stringent than the conditions of deposition.


319-7 4.0KV X500 19mm
10µm


319-6 4.0KV X100 19mm
100µm

2.3 - Presentation of the polishing performance obtained

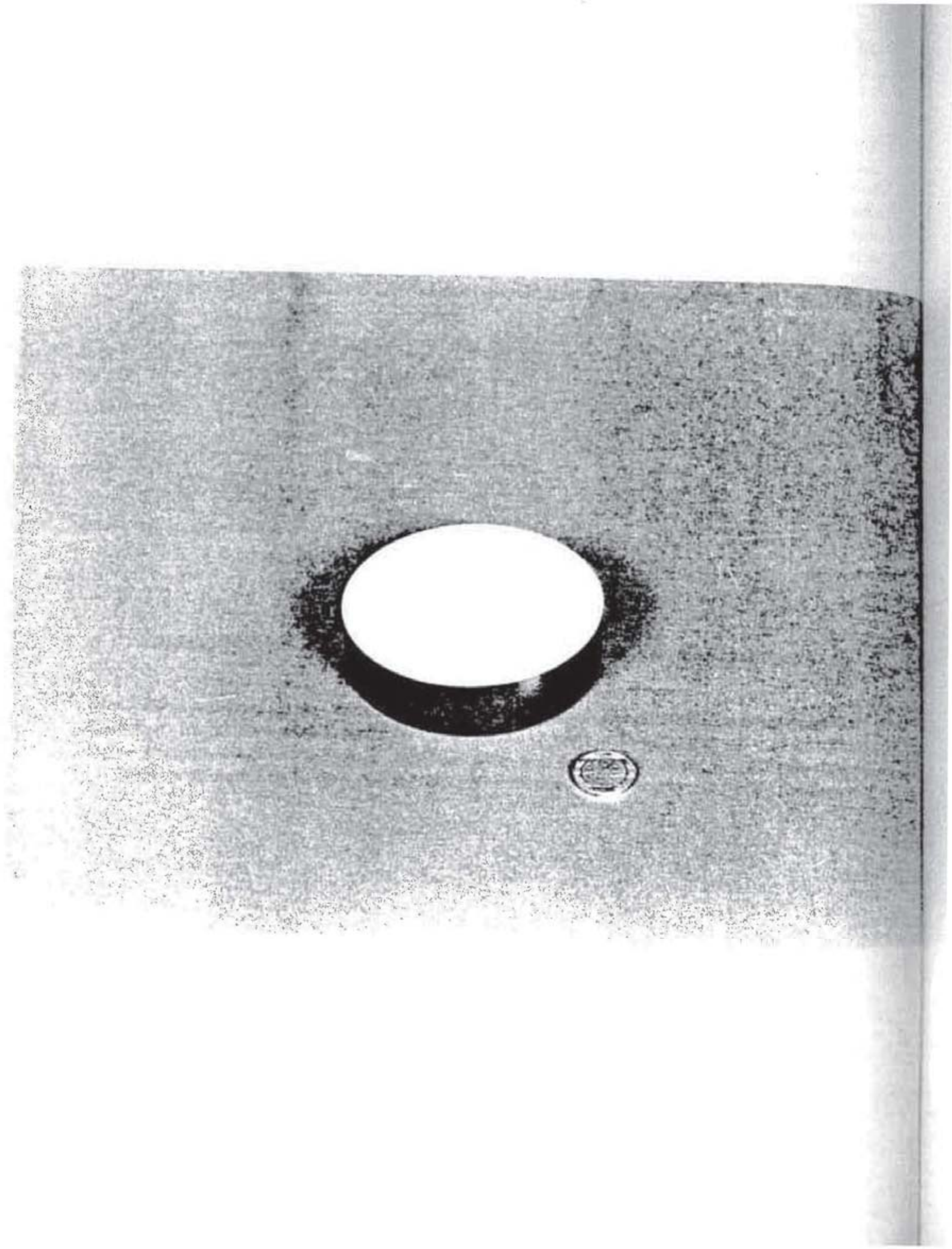
2.3.1 - Quality of coatings depositions achieved and of the polishing performed

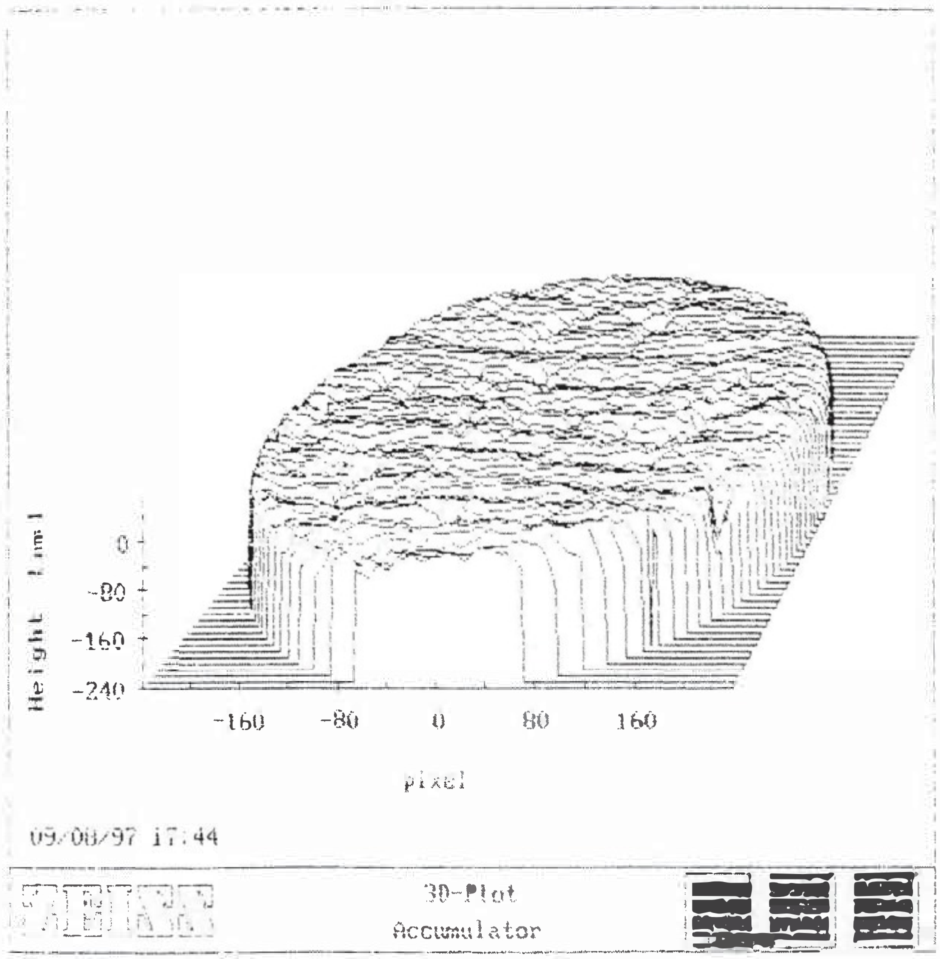
The trials of SiC-PVD depositions performed did not succeed: either the coating deposited cracked during polishing due to the high amount of intrinsic constraints, or it peeled-off. The interface between substrate and coating determines the adherence of the layer: the coating peel-off was observed to be due to a gap between the coating and the substrate. The trials of SiC-CVD depositions were performed successfully by different industrial specialists with regard to the defined success criteria. The coatings deposited on the samples reached the minimum thickness requirement. The interface between the coating and the substrate was observed to be very satisfactory: no gap was observed with microscope between the coating and the substrate (Fig. 4).

Fig. 4: observation of the interface on optical microscope (side view of the sample)

Polishing sequence of the best CVD samples was achieved in a very short time - few hours - which confirms that the thickness of coating deposited was well dimensioned with regard to polishing constraints (Fig. 5). It is to underline that these good results were obtained on different samples coated and polished separately which validates the reproducibility of the performance achieved.

Fig. 5: photo of a SiC-CVD sample aluminium coated fulfilling the performance requirement




Height [nm]
0
-80
-160
-240
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80
160
pixel
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3D-Plot
Accumulator

2.3.2 - Optical performance achieved

Bi-directional Reflectance Distributing Function of the polished samples was measured on CNES scatterometer set-up (Fig. 6). The equivalent microroughness of the surface, deduced from the scattering level recorded is 1.2 nm RMS which is in line with the polishing requirement and is compatible with the optical systems advanced studies requirements.

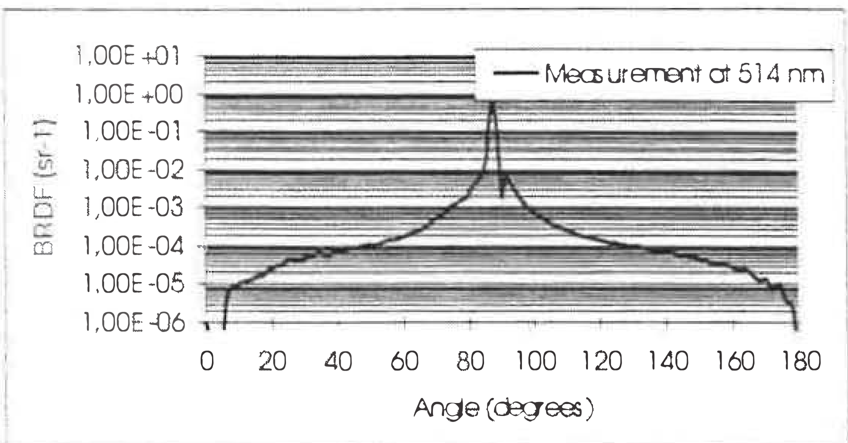

Fig. 6: BRDF measurement of a well polished SiC-CVD sample aluminium coated, illuminated at normal incidence - *(With courtesy of CNES)*

Wavefront Error was measured on a Direct 100 interferometer of MMS facility. A WFE of $\lambda/15$ RMS at λ=633 nm over 95 % of the surface is achieved (Fig. 7).

Fig. 7: WFE of a polished SiC-CVD sample measured at 20°C

Thermoelastic deformation was measured on a sample of sintered SiC coated of SiC-CVD. Measurement was performed in air with using a MMS Direct 100 interferometer. No measurable WFE deformation was observed over a thermal excursion of 80°C hence confirming that bi-metallic effect is lower than the set-up measurement repeatability. The thermal sensitivity is going to be refined soon by measurement under vacuum.

3 - CONCLUSION

The investigations performed by MMS on SiC chemical vapour deposition and on the associated polishing process have highlighted that coating deposition on sintered SiC substrate is a good candidate to reach the optical performance required for the advanced optical systems: scattering level is minimised and polishing is achieved without constraint thanks to the high thickness of coating deposited.

Any step of the process is compatible with an industrial development. It is obvious for polishing as far as standard techniques were used. It is also true for coatings deposition, the coatings having been deposited during industrials cycles in chambers using standard parameters. Chambers for coating optical surfaces up to 2.5 meters of diameter can be found in Europe.

The industrial capacities of productions of the coatings manufacturers are also compatible with the manufacturing of several pieces within a short time.