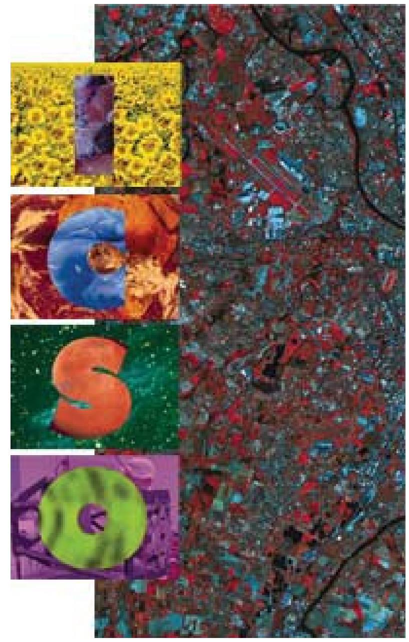
International Conference on Space Optics—ICSO 2000

Toulouse Labège, France

5–7 December 2000

Edited by George Otrio



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International Conference on Space Optics — ICSO 2000, edited by George Otrio, Proc. of SPIE Vol. 10569
105690D · © 2000 ESA and CNES · CCC code: 0277-786X/17/$18 · doi: 10.1117/12.2307943

DEVELOPMENT OF BLACK SCATTERING COATINGS FOR SPACE APPLICATION (ETUDE DE TRAITEMENTS NOIRS DIFFUSANTS POUR APPLICATION SPATIALE)

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RESUME – Dans le cadre d'une action de Recherche et Technologie (R&T), des travaux ont été menés sur les traitements des bords de diaphragme dans le domaine spectral 0,4 à 1 µm. Les principaux axes de l'étude portaient sur l'amélioration des traitements noirs diffusants actuellement disponibles et la recherche d'autres traitements noirs diffusants. Ces travaux ont été accompagnés d'une mise au point d'usinage des bords de diaphragme. La caractérisation (essais thermiques, mesures photométriques, tests d'adhérence) des technologies les plus prometteuses a été effectuée. Les résultats obtenus ont permis de mettre en évidence les diaphragmes en acier, dont l'arête est préalablement polie ou obtenue par rectification améliorée, recouverts d'un dépôt chimique de cuivre noir.

***ABSTRACT** – In the context of Research and Technology (R&T), studies have been performed on the coatings of vane edge in the 0.4 to 1 µm spectral range. The main purposes of the study were to improve the diffusing black coatings available on the market and to look for other diffusing black coatings. At the same time, we have also improved the machining technologies of vane edges. The characterisation (thermal tests, radiometric measurements, adhesion tests) of the most promising technologies has been carried out. The results have pointed out the stainless steel vanes with the edge obtained by polishing or by advanced grinding.*

1 - INTRODUCTION

Signal-to-noise performance arise as being of major importance in many optical systems. It depends on the straylight level so that it requires a special attention during the design of optical systems. The straylight phenomena can also be controlled with special dispositions (black coatings, vanes, geometrical light trap …). In many cases, these dispositions require absorbent and high-performance coatings that must be resistant to space environment and be used on complex and wide surfaces.

Within the context of a study supported by the CNES ("Centre National d'Etudes Spatiales", the French space agency), SODERN was more specially interested in the problems of vane edge coatings in the 0.4 to 1 µm spectral range for star trackers baffles. In order to satisfy larger requirements (Corot, Spot, Hélios…), the possibility to coat wide surfaces was taken into account.

We have oriented our studies mainly towards the improvement of diffusing black coatings available on the market (mineral anodic oxidation, chemical black copper layer on nickel foil…) and the investigation of other scattering black coatings (nickel phosphorous coating, black copper film on thick support…). As the scattering of a vane is directly related to the optical performances of the coating and to the thickness of the edge, we have also improved the thinness of the edge by the development of technologies, chosen among classical and controlled techniques.

2 – TEST DESCRIPTION

We performed the study in two stages. Firstly, we tested different coatings on small circular samples (35mm diameter) ; as the optical performances and the adhesion depend on the substrate of the coating, we chose different substrates. At the same time, we manufactured vane edges with different technologies (inner diameter of 52 mm). Secondly, we made coated vane with the combination of the most promising technologies and we then tested them.

All the performed tests are described in the following paragraphs.

2.1 – The samples of coating

In order to compare the different coatings, we carried out an optical test and an adhesion test on the samples.

The optical measurement consisted of the measurement of the total integrated scatter (TIS) on the SODERN TIS bench. The sample was illuminated by a laser beam (the bench is equipped with two He Ne lasers, 632.8nm and 543.5nm). The hemispherical scatter light was integrated by an integrating sphere. The signal was collected with a silicon cell. Figure 1 presents the photo of TIS bench.

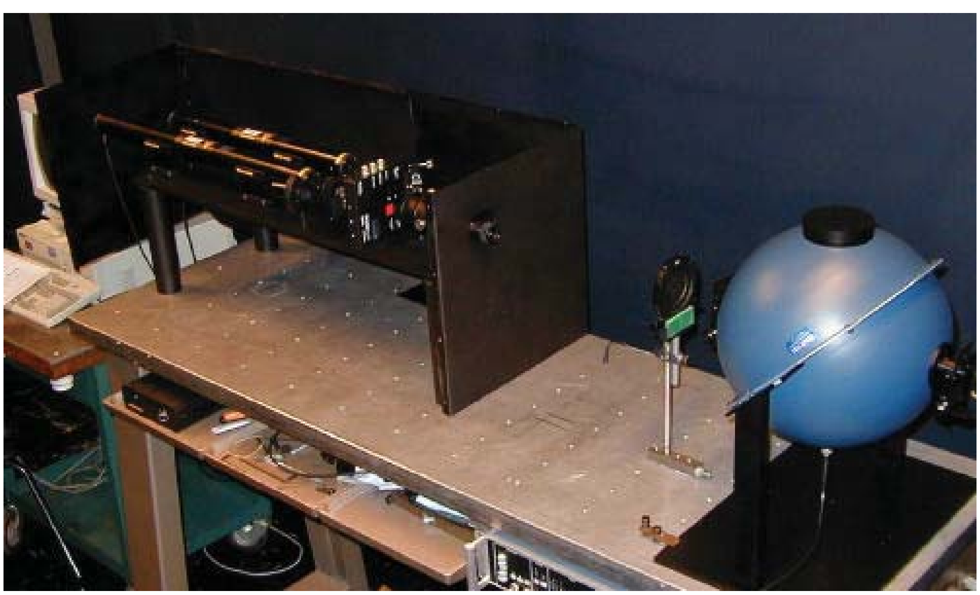


Fig. 1 : Photo of the TIS bench

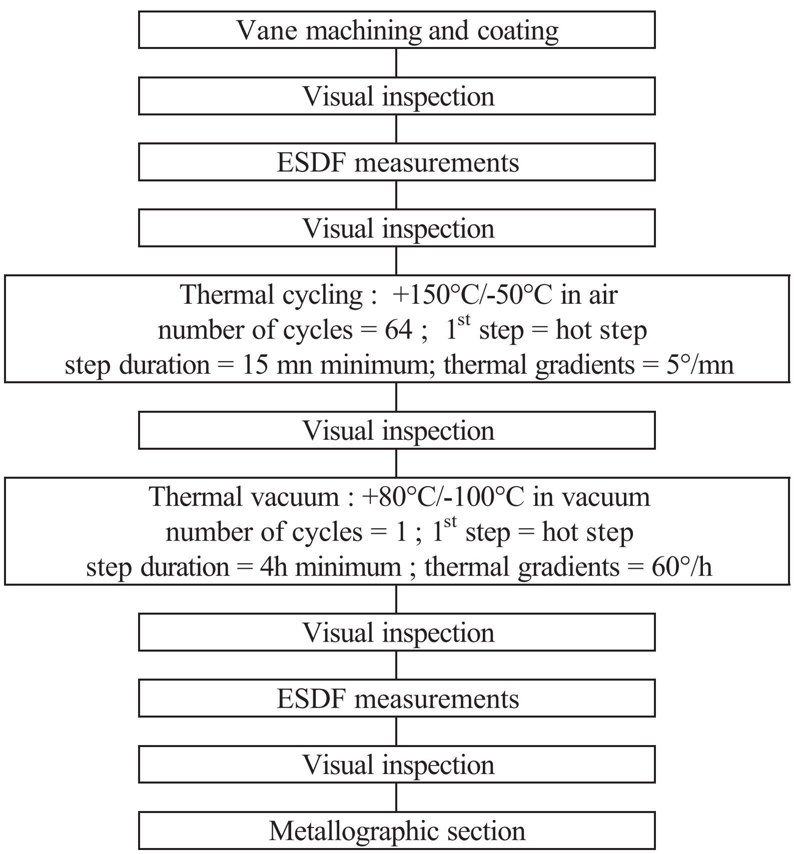
As the black coating must be used for the sharp edge of vanes and should not create particles, its adhesion is an important parameter. We performed the adhesion tests according to the ESA standard ESA-PSS-01-713 with the 3M853 pressure-sensitive tape. The configuration was a $4cm^2$ loading face, an applied load of 5kg for 1 minute and a pulling apart tape and specimen at 0.2cm/min until separation. We thus classified in three groups the different coatings in function of their results : good adhesion (no particle visible on the scotchtape), adhesion acceptable (some particles visible on the scotchtape and adhesion acceptable) and adhesion non acceptable.

2.2 – The samples of vane edge

We compared the various technologies for machining edges with cross-sectional examinations (with the help of a microscope or a scanning electron microscope). To achieve that, we observed the edge and its morphology and measured the thickness.

2.3 – The coated vanes

After the results of the previous studies, we have selected the most promising technologies for machining edges and the most performance black coatings. We made complete coated vanes with the combination of various technologies and we characterised them, according to the test plan described on Figure 2.



measurement of the edge thinness

Fig. 2 : Test plan for the coated vane characterisation

We performed optical tests to measure the scattering of the vanes. Then, we evaluated the behaviour of the vanes in the spatial environment. To achieve, we put them in a thermal environment for 64 cycles from +150°C to -50°C, and in thermal vacuum for one cycle from +80°C to –100°C. We observed the vanes and especially the edge and we performed new optical tests, before and after the environment cycling. We compared the scattering results and we take note of no change. These tests also allowed to control the adhesion of the coating on the sharp vane edges. And at the end, we cut all the vanes for a cross-sectional examination.

The optical test consisted of the measurement of the vane ESDF (Edge Scattering Distribution Function). This parameter characterises the vane by its scattering when it is illuminated and corresponds to the scattered irradiance divided by the incident irradiance. This test was carried out on the SODERN straylight bench. Figure 3 presents a schematic view of the ESDF set-up and Figure 4 shows a photo of the straylight test bench used for the ESDF measurements. For the ESDF test, we completely illuminated the vane edge. The incident beam, coming from a filament lamp (400 W), was collimated and reached the vane with a normal incidence. The detector, a CCD camera, was placed at a distance of 800 mm of the sample and moved around the sample. Different protective screens and light-traps were well-placed with the aim of reducing unwanted straylight.

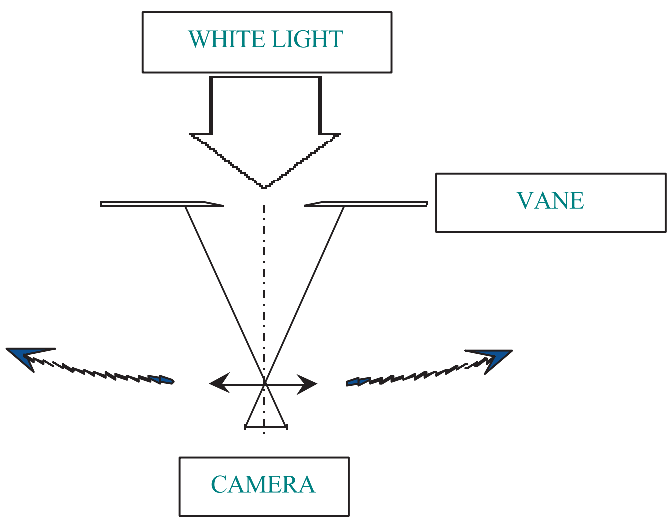


Fig. 3 : Schematic view of ESDF measurements

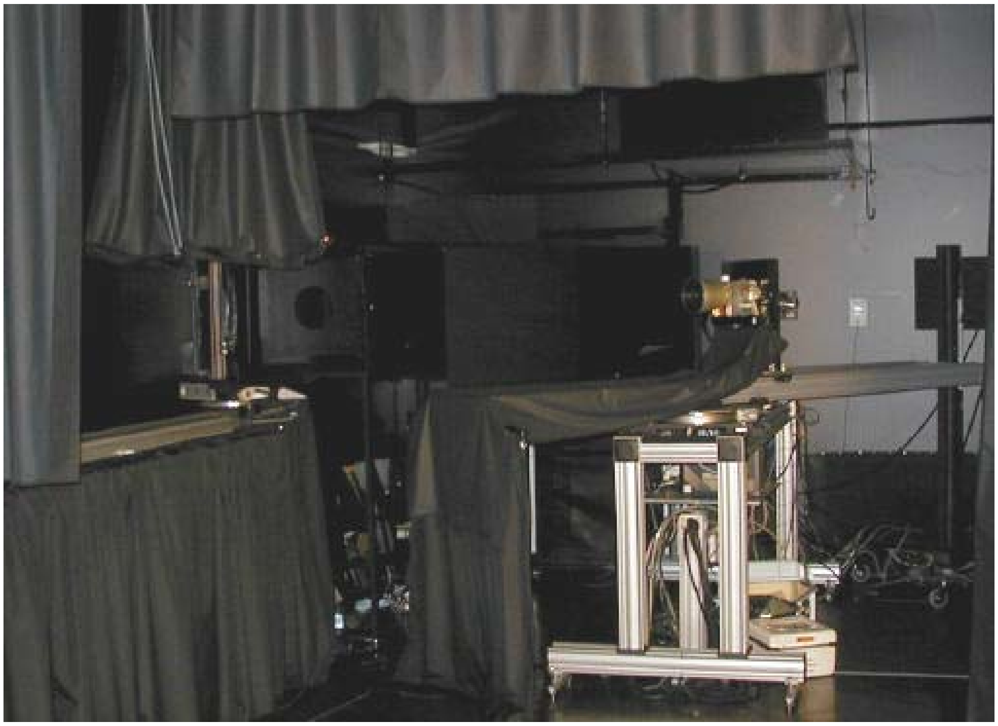


Fig. 4 : Photo of the straylight test bench

3 – TEST RESULTS

3.1 – Black diffusing coatings

We have characterised the different black diffusing coatings in term of scattering, adhesion and thickness. The results of the most interesting coatings are presented in the following table :

Black diffusing coating	*Substrate*	*TIS*	*Adhesion*	*Coating thickness*
standard sulphuric anodic oxidation	aluminium alloy	3.5% - 5%	good	16 µm
variants of sulphuric anodic oxidation	aluminium alloy	2.4% - 3.6%	good	9 - 40 µm
black copper oxide film, chemical deposition	nickel aluminium alloy stainless steel titanium	0.8% - 2.1%	acceptable	5 - 11 µm
black copper oxide film,	stainless steel	3.5%	excellent	5 µm

cathodic arc plasma deposition				
black chromium oxide film, chemical deposition	nickel titanium	2% - 2.3%	acceptable / good	5 - 10 µm
black nickel phosphorous layer	stainless steel aluminium alloy nickel	3.3% - 4.3%	excellent	5 µm

We took the standard sulfuric anodic oxidation as a reference. We have tested different variants of sulfuric anodic oxidation which, on the one hand, allow better scattering performances and, on the other hand, increase the thickness of the coating. The adhesion performances are not altered. The black copper oxide film obtained by chemical deposition, has a weak scattering (between 0.8% and 2.1% in function of the substrate), and a weak thickness (between 5µm and 11µm). The film is less adherent than the sulfuric anodic oxidation. The adhesion is improved by the means of another deposition technology : the cathodic arc plasma deposition, which gives an high adherent and thin (5µm) film but with an increase of the scattering (TIS = 3.5%). The black nickel phosphorous layer has the same performances as the black copper oxide film deposited by arc plasma. The chemical black chromium oxide film has almost the same properties than the chemical black copper oxide film except for the scattering which is lightly less performance (TIS = 2 – 2.3%).

3.2 – Edge machining

In parallel of the coating study, we tested various technologies among the classical and controlled technologies of machining vane edges. The aim was to achieve the thinnest vane edge that could be coated by a scattering black coating with an acceptable level of adhesion.

After a visual selection, we cut the vanes for a cross-sectional examination. We measured the thickness of the edge with the help of microscope and electronic microscope. The results are reported in the following table :

Technology	*Substrate*	*Thickness of the edge*
standard grinding	aluminium alloy	80 – 200 µm
advanced grinding	stainless steel titanium	3 - 7 µm
optical polishing	aluminium alloy stainless steel	3 - 13 µm
ultra-precise machining (with the mean of a monocrystalline diamond)	aluminium alloy	7 µm

The advanced grinding and the optical polishing create thinner edges than those obtained by standard grinding. These two technologies may be used for different substrates. The ultra-precise machining using a monocrystalline diamond, is not easy to implement, so we prefer the two former technologies.

Concerning the use of metal foil, the edge depends on the thickness of the foil and on the machining technology. We have tested different photochemical etching and photochemical electroforming techniques on nickel foil (50µm and 30µm thickness). All of them create edges with a thickness inferior to the thickness of the foil. The morphology of the edges vary according to the techniques.

3.3 – Coated vanes

Among the different technologies for edge machining and among the different coatings, we selected the most promising couples. Visual inspections and scattering measurements, before and after thermal cycling and vacuum, revealed no changes. All the coatings have a sufficient adhesion on the edge of the vanes.

Figures 5 and 6 presents the results of the most performant vanes, for illumination angles with a 0° and 30° incidence. The central peaks, observed in Figures 5 and 6, correspond to the incident beam passing through the vanes. We took as a reference the vane in aluminium alloy with an edge obtained by standard grinding and which is coated with the standard sulfuric anodic oxidation.

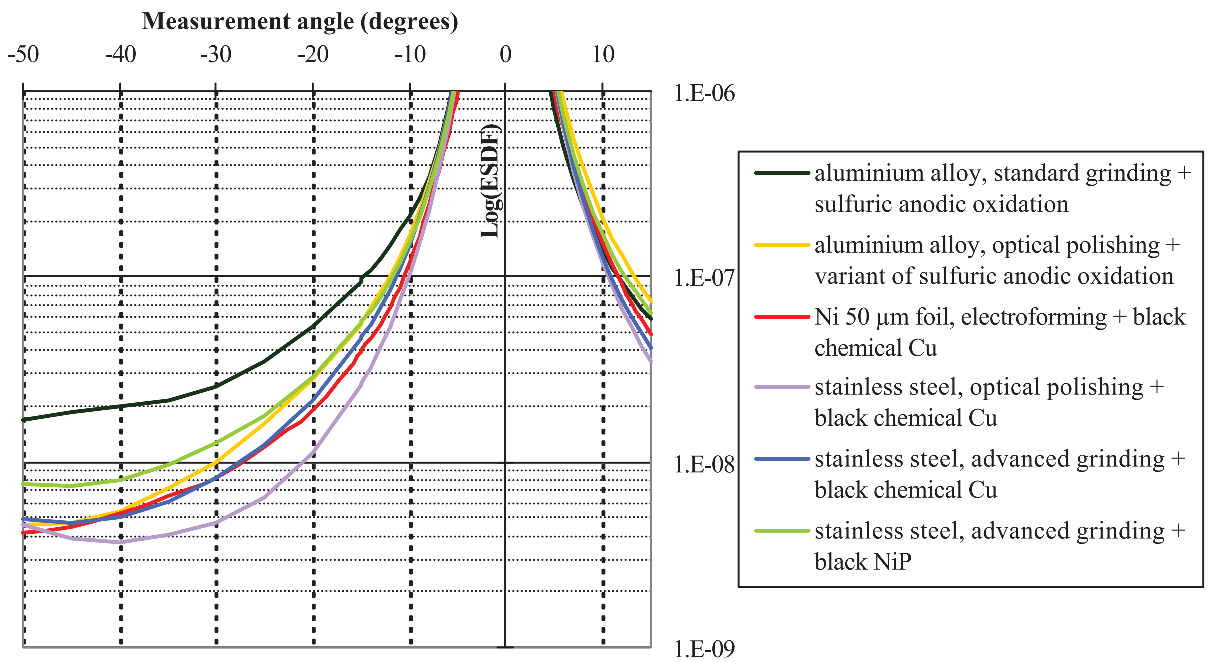


Fig. 5 : Scattering results for 0° incident illumination angle

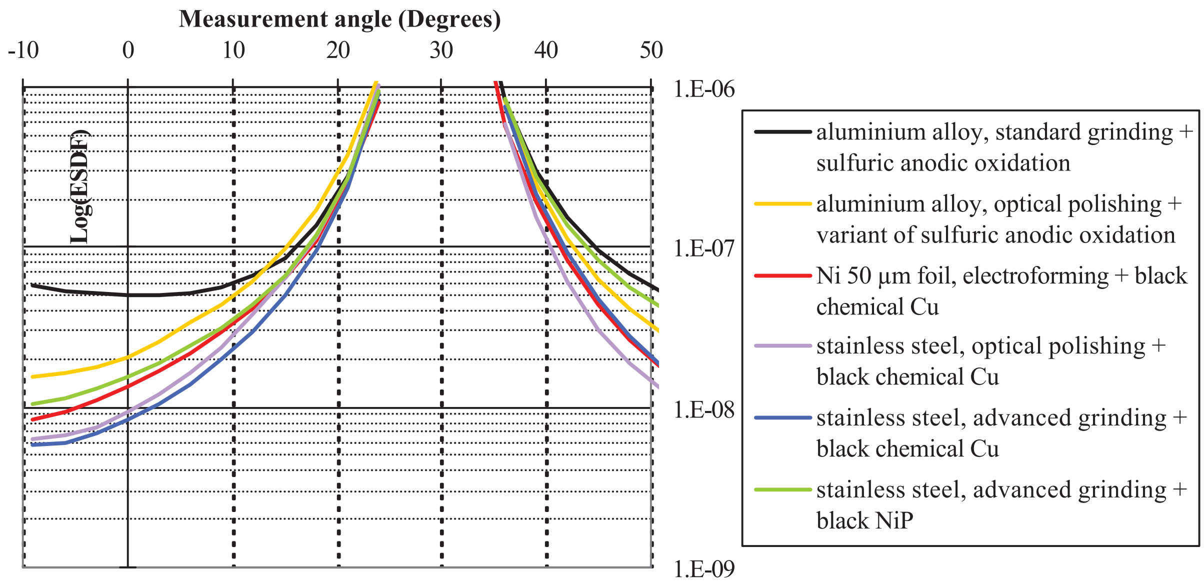


Fig. 6 : Scattering results for 30° incident illumination angle

We note that the scattering performances of the standard vane could be improved by a significant factor, by using other technologies for edge machining and other coatings. Three vanes give the best scattering performances :

- the vane in stainless steel with an optically polished edge and coated with the chemical black copper oxide film,
- the vane in stainless steel with an edge obtained by the advanced grinding and coated with chemical black copper oxide film,
- and the nickel 50µm foil vane with an electroformed edge and coated with the black chemical copper oxide film.

The first vane is slightly better for a 0° illumination angle. The followings, in terms of optical performance, are the vane in 6061 aluminium alloy with a polished edge and coated with a variant of the sulfuric anodic oxidation and the vane in stainless steel with an edge, manufactured by advanced grinding and coated with a black nickel phosphorous film.

4 – CONCLUSION

We have studied and characterised different black diffusing coatings and diverse technologies for edge machining. Each edge machining technology and coating could be chosen in accordance with requirements (scattering, adhesion, thickness, …) and with the utilisation of the vane (inside an optical system, component of a baffle, …). As expected, we have obtained the best results in terms of scattering by using the blackest coating and the thinnest edge.

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