Fabrication of Strongly Curved Aspheric Silicon Carbide Mirrors

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Abstract

TNO Science and Industry has designed and is currently developing the Basic Angle Monitoring Opto-Mechanical Assembly (BAM OMA) [1], which is part of the GAIA spacecraft. In GAIA two telescopes mounted on a slowly spinning satellite will measure the position of the stars with an accuracy much higher as ever done before. Crucial in the system is that the relative angle between the two telescopes should remain stable in the µrad range. The GAIA BAM-OMA system is equipped with two off-axis parabolic mirrors that have to be polished to a high shape accuracy.

1 Introduction

The confirguration of the off-axis parabolic mirror is shown below in Figure 1. The parabolic mirrors are made of non-CVD coated, sintered silicon carbide (SSiC) and needed to be machined to a wavefront error of less than 25 nm RMS and a surface roughness Rq = 6 nm. The main difficulty of this mirror is its small aperture of 20 mm and its small radius of curvature (R = 50.17 mm).

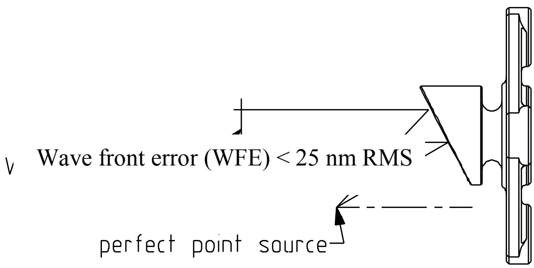


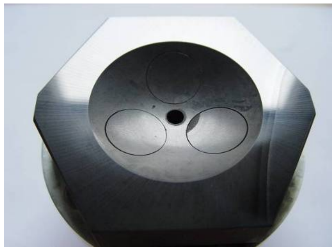
Figure 1: Parabolic mirror used in GAIA BAM-OMA.

TNO Science and Industry and the Leibniz-Institut für Oberflächenmodifizierung (IOM) worked together to produce these mirrors. This paper describes the used techniques and the achieved results.

2 Setup

One of the first steps to facilitate the manufacturing process was to redesign the mirror body. This way a so-called “three in one” setup was possible. Figure 2 shows a photo of an un-polished off-axis test mirror and the ground test assembly used for this research. By using this setup it becomes possible to apply on-axis polishing, which has some advantages over fabricating and measuring three separate off-axis mirrors. The outer edge of the 3in1 setup is used as reference edge needed for alignment purposes for the interferometer and for coordinate measurements.

a)



(b)

Figure 2: (a) individual off-axis SiC mirror, and (b) the used 3in1 setup for on-axis polishing.

2.1 Plasma Jet Machining

Plasma Jet Machining (PJM) is a plasma enhanced chemical etching technology for surface machining [2]. The method is based on a microwave or Radio Frequency excited plasma jet under normal atmospheric pressure or in rough vacuum yielding a high flux of reactive radicals. Material removal is obtained by chemical reactions between the radicals and surface atoms. During the project different plasma jet sources have been developed to do deterministic surface shaping and surface figure error correction over a wide spatial range with nanometer accuracy. The half-width of the almost nearly Gaussian like shaped removal functions reaches from about 0.1 mm to about 10 mm. Maximum volume removal rates of about 50mm³/min have been achieved for fused silica and ultra low expansion glass ULE™. Surface machining is accomplished using the dwell time algorithm on CNC controlled multi-axes systems. Far developed mathematical de-convolution routines are used for creating the machining files.

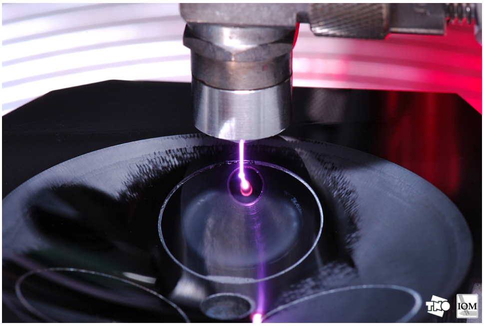


Figure 3: Plasma jet machining on a SiC test mirror.

During plasma jet treatment (Figure 3) no sub-surface damage occurs in contrast to abrasive methods. This advantage makes the plasma jet technology very attractive for the precise manufacturing of especially aspherical and free-form optics. On the other hand the chemical removal mechanism leads to an increase of surface roughness depending on the material and the removal depth. This is caused by preferential etching of the material's structure But at the same time potential subsurface damage is removed.

2.2 Clean-up polishing

The increase in surface roughness can be compensated for by a "clean-up" polishing process [3]. This is done using pitch polishing. Pitch polishing can result in surface roughness values below 1 nm on CVD coated SiC, but during clean-up polishing on sintered SiC the surface roughness is generally about 4 nm Rq (Figure 4).

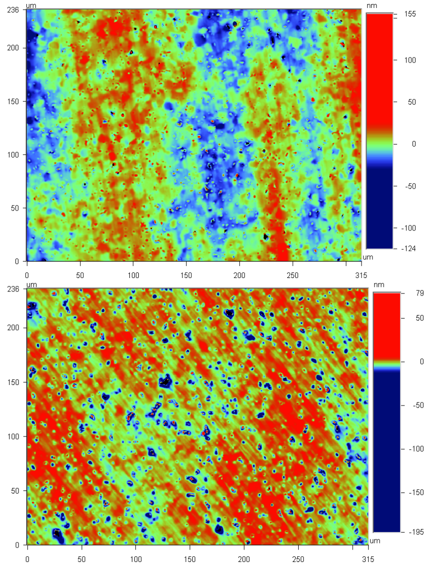


Figure 4: (top) Surface texture after PJM showing the roughened structure, and (bottom) surface texture after pitch polishing. Rq surface roughness values were 10 nm respectively 4 nm. On the right the pores of the non-CVD-coated sintered SiC can be seen.

3 Manufacturing

3.1 Manufacturing scheme

The following manufacturing scheme was applied for the production of the flight mirrors: 1) blank delivery by Boostec Industries, 2) mounting in 3in1 setup at TNO, 3) grinding at Xycarb Ceramics, 4) pre-polishing and metrology at TNO, 5) iterative processing consisting of PJM at IOM and clean-up polishing and metrology at TNO, 6) metrology at TNO, 7) relaxation from 3in1 setup at TNO, 8) final metrology at TNO. It can be seen that quite a lot of actions had to be completed before finalizing the mirrors.

3.2 Results

Figure 5 shows the surface shape errors, measured by an interferometer, after pre-polishing. It can be seen that the PJM process (indicated by PACE in the figure) is capable of very accurate deterministic polishing. However, the clean-up polishing was not shape-maintaining enough in the beginning of the iterative processing.

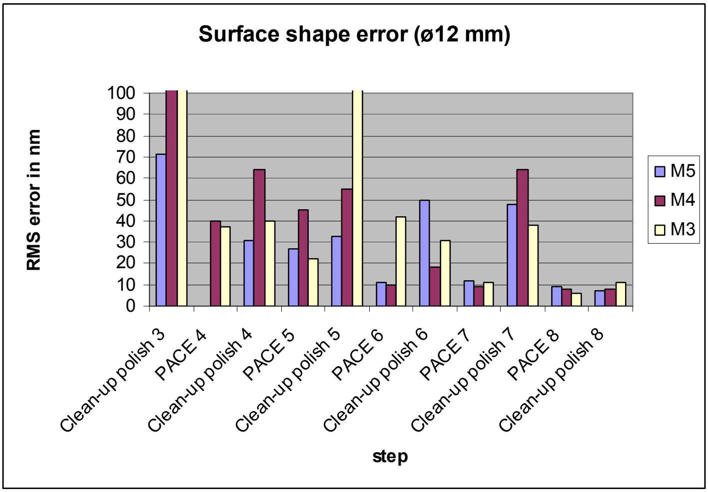


Figure 5: Surface shape errors as measured over a 12 mm diameter aperture. The specification was 12.5 nm RMS (=25 nm WFE) for 10 mm aperture. M3-M5 indicate the mirror numbers.

Figure 6 shows a picture of the flight mirrors in the 3in1 setup before dismounting. The edge cracks that can be seen are not in the mirror surfaces, but in the damaged edges of the holes of the holder.

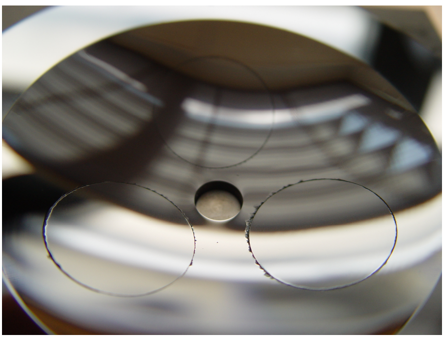


Figure 6: Clean-up polished flight mirrors in the 3in1 setup.

Using this iterative processing scheme we were able to achieve final RMS surface errors of 4.4 nm, 4.4 nm respectively 7.2 nm over a 10 mm effective aperture (note in Fig. 5 that the values are for 12 mm aperture, so slightly higher) and surface roughness values Rq ranging from 3 nm to 6 nm on the three flight mirrors that will be used on the GAIA BAM OMA system.

After dismounting the mirrors were cleaned and prepared for final optical reflective coating. One of the mirrors is shown in Figure 7.

Figure 7: One of the mirrors after dismounting and cleaning.

4 Conclusions

An iterative processing scheme, consisting of Plasma Jet Machining, clean-up polishing and metrology, was developed. Using this processing the three off-axis SiC mirrors for the GAIA BAM OMA were manufactured to within the required surface form specification of 25 nm RMS over 10 mm aperture and surface roughness values ranging from 4 nm to 6 nm Rq.

Acknowledgements

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References

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