

# Fabrication of SiC Off-axis Aspheric Mirror by Using Robot Polishing

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**Abstract.** Two silicon carbide (SiC) lightweight off-axis aspheric mirrors were fabricated by using robot polishing technology. One is a primary mirror with dimension 380mm×328mm, the other is a tertiary mirror with dimension 294mm×238mm. The robot polishing technology is the combination of CCOS technology and a 6-axes industrial robot. The setup of robot polishing system is discussed, and the mirror aspheric grinding, surface polishing and figuring process are reported in this paper. The final surface shape error of primary mirror is 11.4nm RMS, and the tertiary is 12.1nm RMS. The capability of off-axis aspheric mirror fabricating on robot polishing system is verified.

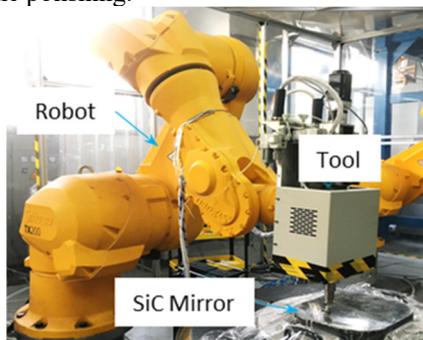
## 1 Introduction

SiC has excellent material property such as high thermal and mechanical stability, which is suitable for optical application in aerospace and next generation lithography. Off-axis aspheric mirrors are widely used in many optical systems [1]. For SiC off-axis aspheric mirrors, the fabricating quality, efficiency and costs are three main problems. The Computer Controlled Optical Surfacing (CCOS) technology has long been recognized as a suitable way to grinding and polishing aspheric surface [2, 3].

In this paper, we introduce the setup of the robot polishing system, and present the process of SiC mirror aspheric grinding and polishing. And the fabrication results are shown.

### 1.1 Robot polishing system

We use a Stäubli TX200 heavy duty 6-axes industrial robot as the motion platform. The polishing tool is a spin-orbital due-rotate sub-aperture lap which is mounted on the robot. The polishing force is automatically applied by pneumatic cylinder in order to obtain stable force load during the polishing.



**Fig. 1.** Setup of robot polishing system.

In order to make the robot suitable for CCOS fabrication, we developed a software in VAL3 language which runs

on the robot controller in order to interpret the G-code like polishing path file to the robot moving code.

The specifications of the robot polishing machine are listed below.

- Maximum work range: 2 m
- Trajectory accuracy:  $\pm 0.1$  mm
- Max. tool spin speed: 300 rpm
- Max. tool orbital speed: 200 rpm
- Max. polishing force load: 30 N
- Capability: plane, sphere, asphere and freeform surface's grinding and polishing

### 1.2 Specification of the SiC mirrors

The primary and tertiary mirrors are both high order off-axis aspheric mirrors with a rectangular shape. The dimension of the primary mirror is 380mm×328mm, and the tertiary mirror is 294mm×238mm. The material is reaction-burned silicon carbide (RB-SiC). The requirement of surface shape error is  $\lambda/50$  RMS for these two mirrors ( $\lambda=632.8$ nm).

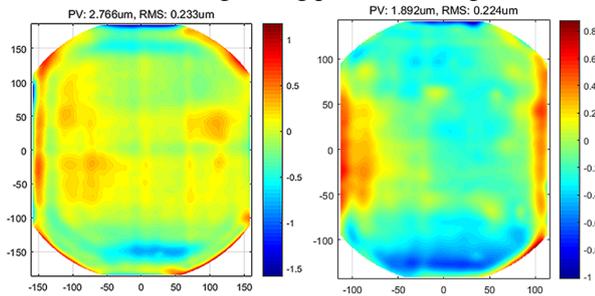
The initial surface is the best fitting sphere, so the aspheric deviation is quite large. The initial shape error of the primary mirror is 0.2mm PV, and the tertiary mirror is 0.08mm PV. So before the polishing, the aspheric grinding is used in order to remove the large surface shape error.

## 2 Aspheric grinding of SiC mirrors

In grinding, the copper pad is used in order to remove the bulk errors, tool marks and sub-surface damages. The pad size is from 15mm to 50mm in diameter, determined by the spatial frequency of the surface shape error that needs to be removed. The diamond abrasives with different particle sizes are used in different phases. There are four sizes of abrasives, which are W40, W20, W10 and W5, used in grinding.

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The surface shape is measured by LEITZ ultra CMM in the grinding. We developed a program to analysis the error map by using the multi dimension optimize algorithm. The surface shape error can be reduced to about 2um PV after grinding process, see figure 2.



**Fig. 2.** Surface shape error after grinding. (Left: primary mirror, PV 2.8um. Right: tertiary mirror, PV 1.9um)

### 3 Aspheric polishing of SiC mirrors

Polishing process includes SiC substrate polishing before surface modification, Si substrate polishing after surface modification, and surface figuring. Surface modification process is an efficient way that can improving SiC surface compactness by depositing a thin layer of Si in the surface.

In SiC substrate polishing, the material of polishing pad is polyurethane, and the abrasive is W2 diamond polishing slurry. The main goal is to polish the surface to make it suitable for surface modification, and reduce surface shape error. By using the robot polishing, the surface shape error can be reduced to  $\lambda/10 \sim \lambda/20$  RMS, and the surface roughness can be reduced to less than 10nm Ra. Figure 3 shows the polishing of primary mirror.



**Fig. 3.** Primary mirror substrate polishing by robot.

Ion beam assisted deposition method is used in surface modification. There is about 10 $\mu$ m thickness Si layer deposited in the SiC substrate surface. The surface shape error is almost maintained the same after the surface modification, but the roughness is increased due to the deposition. So the mirror surface need to be re-polishing.

The final surface figuring is completed by combine the robot polishing and magnetorheological finishing (MRF). The MRF is used to achieve high accuracy figuring and the robot polishing is used to smoothing the surface to remove middle-high spatial frequency shape error. The finished mirror surface is shown in figure 4.

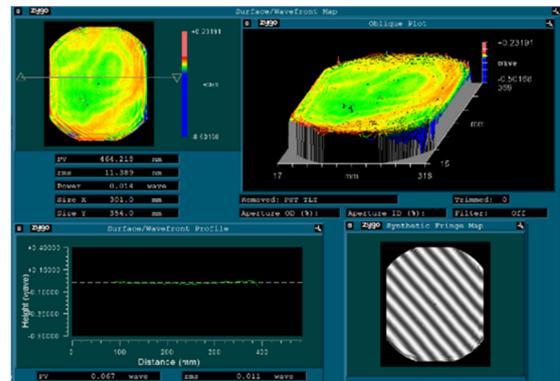
During polishing, the aspheric surface shape error is measured through computer generated holograph (CGH) null-compensation interferometry. A 6 inch Zygo Verifire interferometer with 1K $\times$ 1K pixels CCD is used in the metrology.



**Fig. 4.** The finished mirror surface. (Primary mirror)

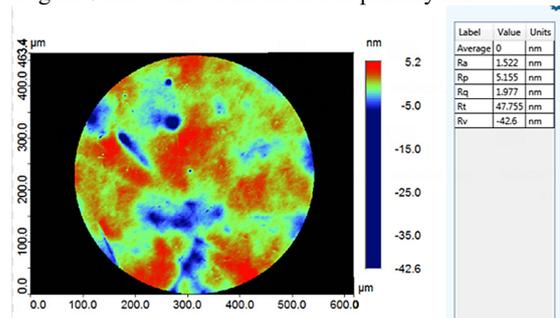
### 4 Results and discussion

Through several iteration of MRF figuring and robot polishing, the surface shape error can be reduced to satisfied the requirement. The surface shape error for primary mirror is 11.4nm RMS (see figure 5), and for tertiary mirror is 12.1nm RMS (not show here).



**Fig. 5.** Final surface shape error of primary mirror.

Surface roughness is also measured by using Bruker white light interferometer, and the roughness is about 1.5nm~3nm in Ra. Figure 6 show one of the results of primary mirror.



**Fig. 6.** Surface roughness of primary mirror.

### References

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