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INTERNATIONAL COLLABORATION FOR SILICON CARBIDE MIRROR POLISHING AND DEVELOPMENT

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ABSTRACT

For research and development of Silicon Carbide (SiC) mirrors, the Korea Astronomy and Space Science Institute (KASI) and National Optical Astronomy Observatory (NOAO) have agreed to cooperate and share on polishing and measuring facilities, experience and human resources for two years (2014-2015). The main goals of the SiC mirror polishing are to achieve optical surface figures of less than 20 nm rms and optical surface roughness of less than 2 nm rms. In addition, Green Optics Co., Ltd (GO) has been interested in the SiC polishing and joined the partnership with KASI. KASI will be involved in the development of the SiC polishing and the optical surface measurement using three different kinds of SiC materials and manufacturing processes (POCO^{TM}, CoorsTek^{TM} and SSG^{TM} corporations) provided by NOAO. GO will polish the SiC substrate within requirements. Additionally, the requirements of the optical surface imperfections are given as: less than 40 um scratch and 500 um dig. In this paper, we introduce the international collaboration and interim results for SiC mirror polishing and development.

Key words: Silicon Carbide (SiC) mirrors, polishing and measurement, international collaboration

1. INTRODUCTION

In order to install an optical system on a large opto-mechanical equipment or payload for a satellite, the weight of the optical system should be light. Therefore, several mirror materials have been studied to reduce the areal density, defined as the material weight per unit area. Simultaneously, general astronomical and satellite optical systems requires high quality optical performances such as diffraction limited and greater stability under high stress (sometimes shocks) and vibration environments. The Hubble Space Telescope used ULE^{TM} (Ultra Low Expansion) material for its primary mirror (Montagnino 1986) and the Gemini Telescope used Zerodur^{TM} for its secondary mirror (Mountain 1998). Their areal densities were 180 kg/m^2 and 47 kg/m^2, respectively (Kendrick & Stahl, 2008). Recently, JWST (the James Webb Space Telescope) utilized Be segmented primary mirrors with 14.5 kg/m^2 of areal density (Kendrick & Stahl, 2008).

To reduce areal density, Silicon Carbide (SiC) mirror material has been studied from POCO^{TM} (POCO Graphite Inc., 2004), CoorsTek^{TM} (CoorsTek, 2004) and SSG^{TM} (SSG Precision optronics, Inc., 2004). The lowest density developed for SiC mirror material is 7.5 kg/m^2 (Postman et al. 2010) and it is 24 times lower than that of the primary mirror of HST.

Benefits of SiC mirrors compared to conventional glass segments reveal a support structure complexity that is lighter, stiffer and simpler. The National Optical Astronomy Observatory (NOAO) had a development program for potential primary mirror segments made of SiC material for the Giant Segmented Mirror Telescope (GSMT) over a decade ago (Cho et al., 2004). During the study period, NOAO conducted a trade-off study for optomechanical analysis for mounting of hexagonal primary mirror segments of 1.4 meters at point to point. In the study, the overall mounting of SiC mirrors reveals simple and relatively few structures compared to the mount of glass mirrors.

Although SiC has outstanding physical properties, the high hardness of the material produces difficulties when polishing the surfaces. Therefore, a sequential approach is required to polish such a hard material from the small the size of coupons to the large size of mirror substrates. The Korea Astronomy and Space Science Institute (KASI) and NOAO have a common interest in developing technologies for polishing and measuring the SiC substrate.

In this paper, the KASI-NOAO collaboration program is introduced in Chapter 2. Chapter 3 presents the optical surface requirements, experimental preparation and interim results. Implications and the future plan is sum-

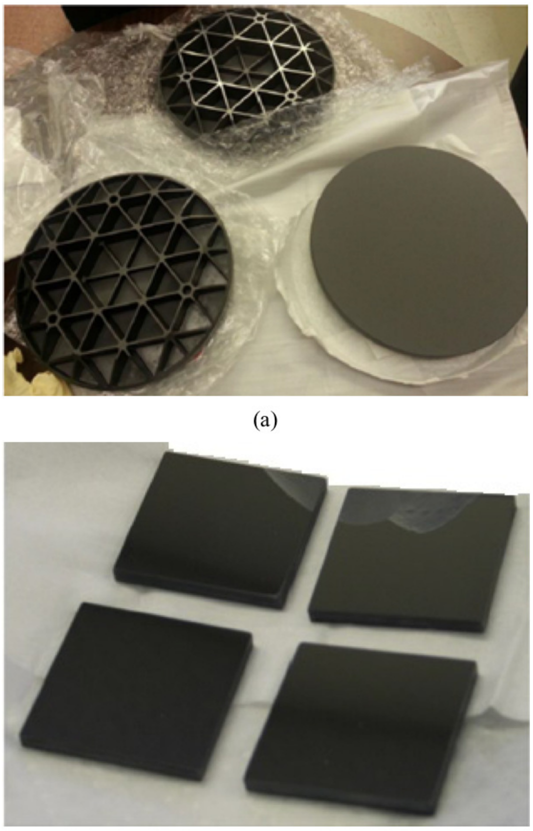


Figure 1. Delivered (a) SiC mirrors and (b) coupons

Table 1
SiC blanks ID information

	Mirror part	Mirror serial	Coupon 1	Coupon 2
SSG	7090401	N/A	325	337
POCO	19752	21347	P01	P02
CoorsTEK	6130317	7851805-4	3	4

Table 2
Development schedule for KASI-NOAO collaboration

Items			Due Date
SSG	Coupon	Making Jig	May. 2014
		Polishing	Aug. 2014
		Measurement	Aug. 2014
	Mirror	Making Jig	Jul. 2014
		Polishing	Dec. 2014
		Measurement	Dec. 2014
CoorsTEK	Coupon	Polishing	Mar. 2015
		Measurement	Mar. 2015
	Mirror	Polishing	May. 2015
		Measurement	Jun. 2015
POCO	Coupon	Polishing	Jun. 2015
		Measurement	Jul. 2015
	Mirror	Polishing	Aug. 2015
		Measurement	Sep. 2015
Environmental Testing		Preparation	Sep. 2015
		Testing	Oct. 2015
	Report		Dec. 2015

marized in Chapter 4.

2. PROGRAM OVERVIEW

KASI and NOAO have established a Letter of Intent (LOI) to have a collaborative program related to optical technology exchanges (Nam & David, 2014). According to this Letter, the two national institutes agreed to collaborate effectively for a 2-year SiC development program. Each institution raised funds to share their resources, such as staff labor, the loan of 3 SiC mirrors from NOAO to KASI, and so forth. The 3 mirror blanks were from 3 different vendors: POCO^{TM}, CoorsTek^{TM} and SSG^{TM}. The SiC material development program of NOAO was held in 2004 (Cho et al., 2004) in order to determine suitable material for the primary mirror of GSMT. However, unfortunately, SiC material was not implemented for the GSMT primary mirror segments due to its limited heritage compared to glass or glass ceramic mirrors.

To loan the substrate, NOAO sent 3 SiC blanks with coupons to KASI in January, 2014. Mirror ID numbers are engraved and Coupon IDs are printed on the back side. The delivered mirrors and coupons are displayed in Fig. 1 and information of the IDs are summarized in Table 1.

In this collaboration, the deliverables are the 3 polished SiC mirrors and test measurements for each of the SiC mirrors. In order to accomplish polishing and metrology development, KASI has total responsibility to develop SiC polishing and metrology development and supervise environmental testing. In addition, NOAO provides technical assistance and fulfills evaluation of polishing performance. For polishing of the mirrors, Green Optics Inc., (GO) prepares appropriate polishing equipment and polish on the substrate.

We identified the possible risks over the whole development period. The primary item is the environmental testing chamber and relevant equipment. Currently KASI has not fully equipped a facility with thermal-vacuum chamber, pump and vacuum gauge, etc. KASI will mitigate the risk to prepare a thermal-vacuum facility or borrow an equipped facility no later than Sep. 2015. Expected development tasks and the schedule are summarized in Table 2.

3. TECHNICAL VIEWPOINT

3.1. Optical Surface Requirements

Surface figure errors should be measured by an appropriate mount specified with the optical surface facing vertically upward supported on three tooling balls placed under the 12 mm diameter holes on the rear surface of the mirror. Surface quality was defined by following five

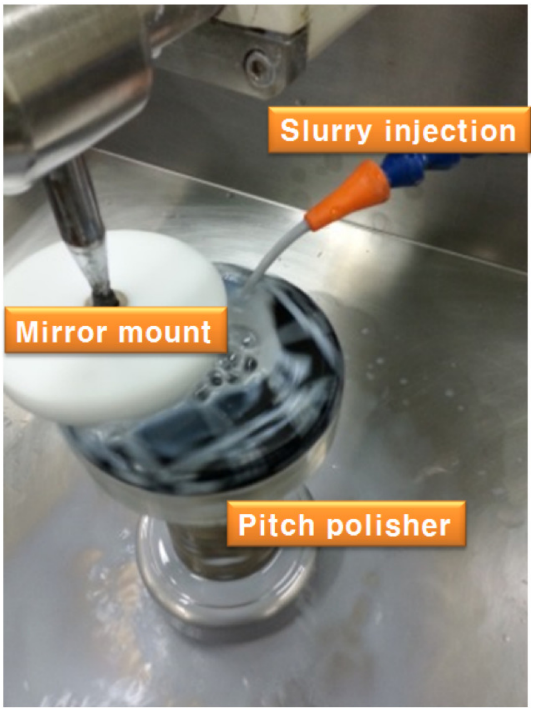


Figure 2. Pitch polisher, mirror mount and slurry injection system for polishing flat optical surfaces

categories.

- Surface figure error should be less than 20 nm rms
- Surface roughness should be less than 2 nm rms
- Surface imperfections should be less than 40 um scratch and 500 um dig
- Subsurface damage be minimized through best efforst
- Structure function should provide for an optical surface

3.2. *Polishing Equipment*

The optical surface shall be nominally flat. Therefore a conventional pitch polisher could be used to polish both coupon and mirror. The pitch tool, mount and slurry injection components are summarized in Fig. 2.

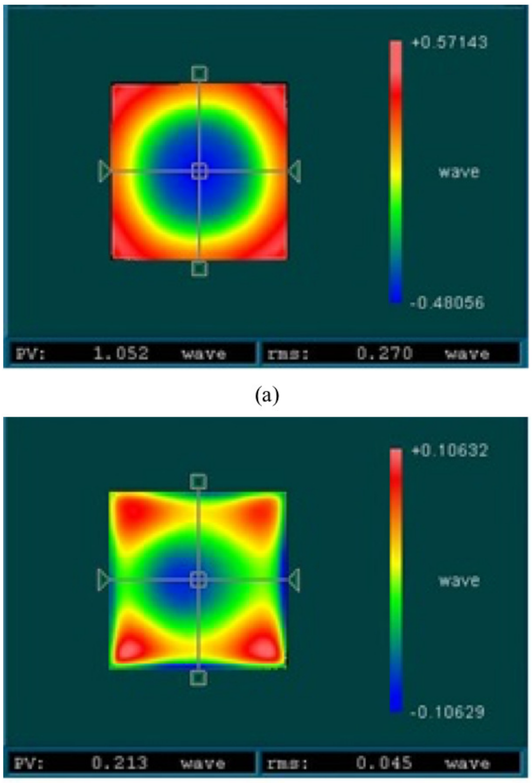
3.3. *Interim Results*

The measured SiC surfaces prior to polishing were approximately 170 nm rms (=0.270 waves; 632.8 nm light sources) as shown in Fig. 3(a). Over only 2 days, the polished surface figure was down to about 28 nm rms (=0.045 waves) as shown in Fig. 3(b).

The micro-roughness was measured at 0.5 nm Ra for the sample area of 9.4 x 8.6 um^2 as depicted in Fig. 4. The area of interest to measure the roughness shall be defined by the application of the polished mirror.

4. IMPLICATIONS AND FUTURE PLANS

During polishing and measurement, KASI was able to successfully control a set of polishing input parameters and machine settings for measurement. NOAO has proposed adequate measurement areas, GO polishes and measures coupon surfaces. Based on these close work associations, the international collaboration has been well established to build up of core technology for SiC surface polishing and measurement. Collaborators will make an effort to extend our experience in SiC optical surface characteristics, the optical treatments and optical metrology. For example, the SiC mirror would be fully optimized, the size of mirrors would be larger than 500 mm in diameter and the surface shape could be curved to off-axis and aspherical shapes.



(a)

(b)

Figure 3. (a) Initial and (b) interim figure error

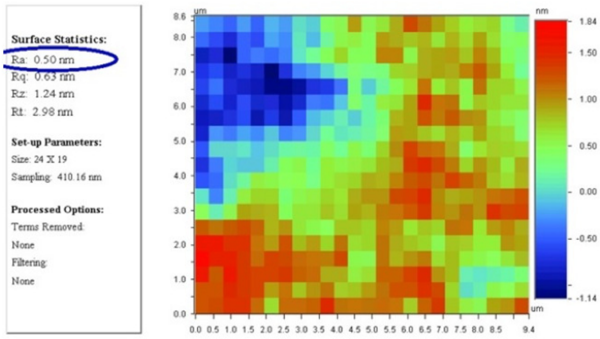


Figure 4. Interim micro-roughness

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