Tool Influence Function (TIF)  
Characteristics of SiC mirrors  

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1. Program Overview

- Collaboration with NOAO, KASI and GO
  - KASI: Total responsibility of development for SiC polishing and measurement
  - NOAO: Evaluation and technical assistances
  - GO: Polishing and measurement
- Study Period: 2014.1.1 ~ 2015.12.31 (2 years)
- Deliverables: 3 SiC polished mirrors
1. Program Overview

- **Surface quality**
  - Surface figure error: less than **20 nm RMS**
  - Surface roughness: less than **2 nm RMS**
  - Surface imperfection: less than 40 um scratch, 500 um dig
  - Subsurface damage: use best efforts to minimize
  - Structure function: provide (determined by collaboration with NOAO)

- **Measurements**
  - Surface figure error was measured by 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

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1. Program Overview

<table>
<thead>
<tr>
<th>Risk and effectiveness</th>
<th>Prob.</th>
<th>Imp.</th>
<th>Mitigation plan</th>
<th>Consortium</th>
<th>Status (Due)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rick: Environmental testing</td>
<td></td>
<td></td>
<td>Preparation of the facility</td>
<td>KASI NOAO GO</td>
<td>Finish ('15.09)</td>
</tr>
<tr>
<td>▪ Not fully equipped facility in KASI</td>
<td>L</td>
<td>M</td>
<td>- Find funding sources to purchase</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Effectiveness</td>
<td></td>
<td></td>
<td>Adjust testing plan</td>
<td>NOAO KASI</td>
<td>Finish ('15.11)</td>
</tr>
<tr>
<td>▪ Not fully certified mirrors in operation condition</td>
<td></td>
<td></td>
<td>- Mild temperature condition</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
OPTICAL FABRICATION OF COUPONS AND 300 MM SIC MATERIALS
2. Fabrication

SiC collaboration (KASI-NOAO)

3 SiC blanks with coupons shipped to KASI (1/2014)

Mirror ID numbers engraved; Coupon IDs printed at the back.

<table>
<thead>
<tr>
<th></th>
<th>Mirror Part</th>
<th>Mirror Serial</th>
<th>Coupon 1</th>
<th>Coupon 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>SSG</td>
<td>7090401</td>
<td>N/A</td>
<td>325</td>
<td>337</td>
</tr>
<tr>
<td>POCO</td>
<td>19752</td>
<td>21347</td>
<td>P01</td>
<td>P02</td>
</tr>
<tr>
<td>CoorsTek</td>
<td>6130317</td>
<td>7851805-4</td>
<td>3</td>
<td>4</td>
</tr>
</tbody>
</table>

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2. Coupon Polishing - configuration

- **Slurry grain size**
  - 1st stage: 9, 1 um
  - 2nd stage: 6, 1 um

- **Rotation speed**
  - Cam: 21 rpm
  - Spindle: 64 rpm

Pitch polisher

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2. Coupon Polishing - equipment

Finished by MRF
Measured by ASI

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2. Coupon polishing - Figure error of SSG

12.3 nm (req. 20 nm)
2. Coupon polishing - Surface roughness

Coorstek: 0.226 nm rms
POCO: 0.226 nm rms
SSG: 0.226 nm rms

Req. = 2 nm rms
3. Ф 300 mm SiC polishing - configuration

For edge correction:
- SUBA pad (1st stage) → #73 pitch (2nd stage)

SUBA pad

#73 pitch

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3. Ф 300 mm SiC mirror polishing - equipment

Polished by IRP

Measured by ASI

- Optical surface feature using ASI with 3 kinematic mount
- measured by 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

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3. Ф 300 mm SiC polishing – surface figure

- Polished optical surfaces (work in progress for SSG)
  - Coorstek, POCO, SSG (requirement: < 20 nm rms)
3. Ф 300 mm SiC polishing – surface roughness

- Surface roughness measurement (work in progress)

Coorstek surfaces
0.58 ± 0.03 nm rms
(Data taken by 5 different positions)

POCO surfaces
0.50 ± 0.02 nm rms
(Data taken by 5 different positions)

SSG surfaces
2.72 ± 0.46 nm rms
(Data taken by 2 different positions)
TIF CHARACTERISTICS OF VARIOUS SIC MATERIALS
4. TIF model development

Preston Equation: \( \Delta z = \alpha PV \Delta T \) (Depth of TIF vs. Input variables)

\[ P(x, y) = \frac{e^{-\frac{1}{2}\left(\frac{x}{\sigma_x}\right)^2 + \left(\frac{y}{\sigma_y}\right)^2}}{2\pi \sigma_x \sigma_y} \]

**Definition of Velocities**

**Corresponding Preston Eq.**

\[ \Delta z = \kappa \frac{e^{-\frac{1}{2}\left(\frac{\Delta x^2 + \Delta y^2}{\sigma_x^2 + \sigma_y^2}\right)}}{2\pi \sigma_x \sigma_y} \left| \mathbf{V}_x + \mathbf{V}_w \right| \Delta t \]
## 4. Polishing tool – requirement and specification

### OVT (Orthogonal Velocity Tool)

<table>
<thead>
<tr>
<th>Items</th>
<th>Detailed items</th>
<th>Ranges / Spec.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Req.</strong> TIF shape</td>
<td></td>
<td>Gaussian shape</td>
</tr>
<tr>
<td>Wheel</td>
<td>Rotation speed</td>
<td>15~1000 rpm</td>
</tr>
<tr>
<td></td>
<td>Contact width</td>
<td>3.8 ~ 3.9 mm</td>
</tr>
<tr>
<td></td>
<td>Contact area</td>
<td>6.0 ~ 6.5 mm²</td>
</tr>
<tr>
<td>Spec. Rotational axis</td>
<td>Rotation speed</td>
<td>4~60 rpm</td>
</tr>
<tr>
<td>(Radial direction)</td>
<td>Motion control item</td>
<td>Rotation angle</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Dwell time</td>
</tr>
<tr>
<td>Load cell</td>
<td>Measurement ranges</td>
<td>Min.: 0.1 psi</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Max.: 10 psi</td>
</tr>
<tr>
<td>Development</td>
<td>KASI, SphereDyne, YoonSeul</td>
<td></td>
</tr>
</tbody>
</table>

**Development**

KASI, SphereDyne, YoonSeul

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TIF polishing head

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4. TIF generation on coupon

Input parameters

<table>
<thead>
<tr>
<th>Force</th>
<th>Force (kgf)</th>
<th>0.07</th>
<th>0.09</th>
<th>0.11</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pressure (psi) [P]</td>
<td></td>
<td>17.27</td>
<td>20.10</td>
<td>23.33</td>
</tr>
<tr>
<td>Wheel rotation speed</td>
<td>Wheel rotation speed (rpm)</td>
<td>17</td>
<td>23</td>
<td>29</td>
</tr>
<tr>
<td>Linear rotation speed of wheel (m/sec) [V]</td>
<td>0.086</td>
<td>0.117</td>
<td>0.147</td>
<td></td>
</tr>
<tr>
<td>Dwell time</td>
<td>Dwell time (sec)</td>
<td>5</td>
<td>10</td>
<td>15</td>
</tr>
<tr>
<td>Dwell time (hour) [ΔT]</td>
<td></td>
<td>0.0014</td>
<td>0.0028</td>
<td>0.0042</td>
</tr>
</tbody>
</table>

Generated TIF patterns

Coorstek

POCO

SSG

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4. Preston equation and TIF comparison

Depth of TIF vs. Input variables

\[ \Delta z = \alpha PV \Delta T \]  (Preston Eq.)

\( \Delta z \): Depth of TIF
\( \alpha \): Coefficient of material removal
\( P \): Pressure of wheel
\( V \): Relative velocity between wheel and workpiece
\( \Delta T \): Dwell time

TIF experimental example

Comparison (Model vs. Exp.)

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4. TIF analysis

Corresponding coef. of material removal ($\alpha$)
- Coorstek: 7.28 (um/(psi·hour·m/sec))
- POCO: 6.57 (um/(psi·hour·m/sec))
- SSG: 6.57 (um/(psi·hour·m/sec))
4. TIF analysis – relationship between parameters

Preston coefficient and TIF depth

![Graph showing the relationship between Preston coefficient and TIF depth. The graph plots removal coefficient (um/psi hour to m/sec) on the x-axis and depth (nm) on the y-axis. Different symbols represent data from SSG, Poco, and CoorsTek.]
PREPARATION OF ENVIRONMENTAL TESTING

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4. Preparation of environmental testing

Preliminary design for environmental testing
(-40, -10, +20 degrees)

Transmission curve on Chamber window

300 mm SiC

300 mm Window (t: 30 mm)

Interferometer

Mechanical mounting specifications for interferometer movement

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Specifications</th>
</tr>
</thead>
<tbody>
<tr>
<td>X Stroke</td>
<td>±90mm</td>
</tr>
<tr>
<td>Y Stroke (manual)</td>
<td>±5mm</td>
</tr>
<tr>
<td>Z Stroke</td>
<td>±90mm</td>
</tr>
<tr>
<td>Tilt (manual)</td>
<td>±3 (±5mm)</td>
</tr>
<tr>
<td>Load</td>
<td>100kgf</td>
</tr>
<tr>
<td>Accuracy</td>
<td>10μm</td>
</tr>
<tr>
<td>Repeatability</td>
<td>5μm</td>
</tr>
<tr>
<td>Speed</td>
<td>0.05~20mm/sec</td>
</tr>
<tr>
<td>Linearity</td>
<td>±0.07mm/190mm</td>
</tr>
</tbody>
</table>

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RESULTS AND IMPLICATIONS
5. Results and Implication

- International collaboration efforts among NOAO, KASI and GO demonstrated a successful output for SiC mirrors.
- We developed tools for the optical surface control, identified issues and discussed to improve the technology for SiC mirrors.
- Summary of results of coupons and 300 mm SiC mirrors provided by NOAO (work in progress).

<table>
<thead>
<tr>
<th></th>
<th>Coorstek</th>
<th>POCO</th>
<th>SSG</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coupons</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Surface figure (nm rms)</td>
<td></td>
<td></td>
<td>12.3</td>
</tr>
<tr>
<td>Roughness (nm rms)</td>
<td></td>
<td>0.092</td>
<td></td>
</tr>
<tr>
<td>300 mm</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Surface figure (nm rms)</td>
<td>11.825</td>
<td>18.161</td>
<td>28.884</td>
</tr>
<tr>
<td>Roughness (nm rms)</td>
<td>0.58 ± 0.03</td>
<td>0.50 ± 0.02</td>
<td>2.72 ± 0.46</td>
</tr>
<tr>
<td>Preston coefficient (um/(psi·hour·m/sec))</td>
<td>7.28</td>
<td>6.57</td>
<td>6.57</td>
</tr>
<tr>
<td>Polishing status</td>
<td>Polishing finished</td>
<td>Polishing finished</td>
<td>Finalizing</td>
</tr>
</tbody>
</table>

- Present the understandable TIF patterns
  - Established TIF characteristic maps for various SiC mirrors
5. Results and Implication

- Preparation of environmental testing for 300 mm optics
  - Chamber and stitching setup

- Preparation of Phase II planning by NOAO
  - Period: 2016~2018 (3 years)
  - Size: 500 mm in diameter
  - Shapes: Off-axis aspheric, Convex aspheric, Concave aspheric
  - Scope: Development of both polishing and material process
Thank you for your attention