



Mirror polishing technology with Tool Influence Function (TIF) for SiC

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Nov. 19, 2014.

Contents

- 
- **Background: program overview**
 - **Technical viewpoints**
 - : Polishing of Φ 300 mm and coupon
 - : TIF study
 - **Result and Future Plan**

1. BACKGROUND

- PROGRAM OVERVIEW

1. Overview

❖ Collaboration between KASI and NOAO

■ KASI

- SiC development in polishing and testing
- Teamed with Green Optics (GO)

■ NOAO

- Technical support
- Loan 3 SiC blanks ($\Phi 300\text{mm}$) and coupons

❖ Period: January 2014-December 2015 (2 years)

❖ Deliverables: 3 SiC polished and test results

❖ Kickoff meeting: March 2014

1. Overview - Material

SiC collaboration (KASI-NOAO)

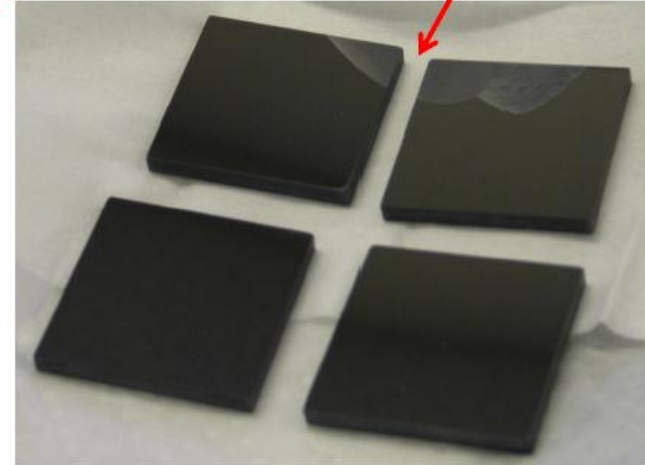
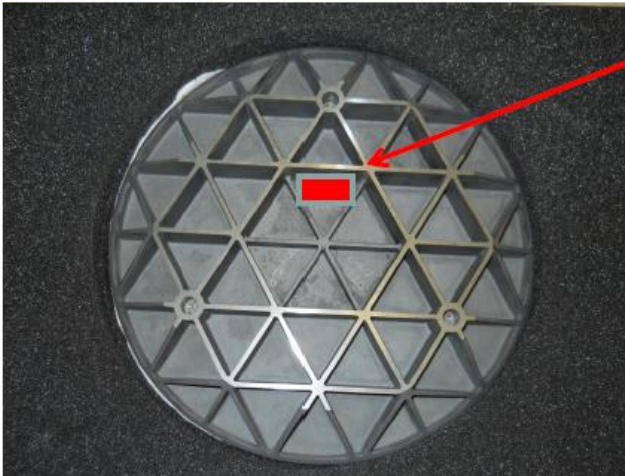
3 SiC blanks with coupons shipped to KASI (1/2014)



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

SiC Mirror and Coupon ID numbers

	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



1. Overview - Optical surface requirements

❖ 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

❖ Surface quality

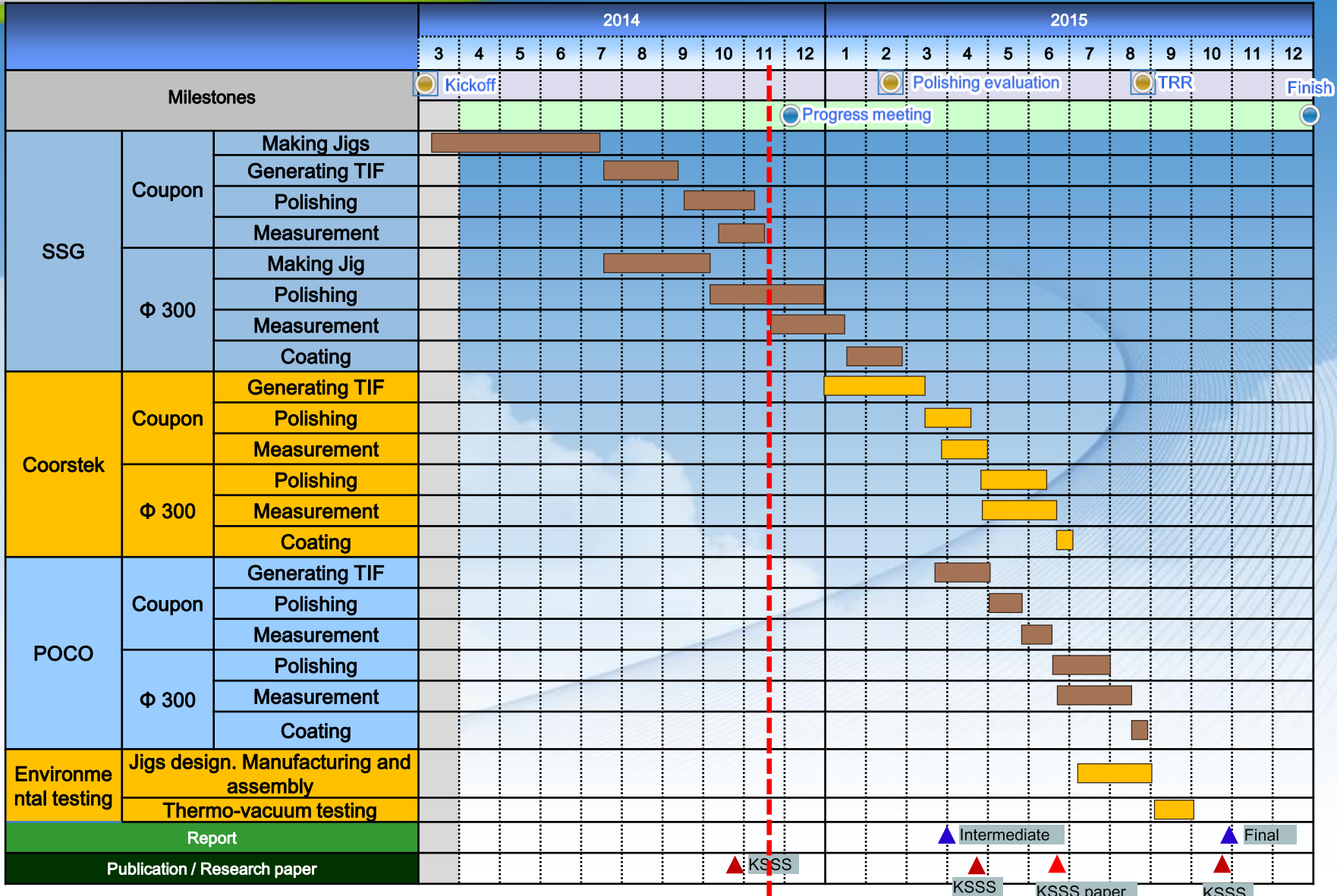
- Surface figure error: less than 20 nm RMS
- Surface roughness : less than 2 nm RMS
- Surface imperfection: less than 40 μm scratch, 500 μm dig
- Subsurface damage: use best efforts to minimize
- Structure function: provide (determined by collaboration with NOAO)

1. Overview - Role and responsibility

No	Category	Description	Role			Responsibility			Review	
			KASI	GO	NOAO	KASI	GO	NOAO		
1	Purpose	Investigate polishability	C	E	A	Cr	R	P	FR	
2		Provide polished prototypes	C	E	A	Cr	R	P	FR	
3		Collaborate in design dev. & polishing	C	E	A	Cr	R	P	FR	
4	General	ATP preparation	E,C	E	A,S	R,Cr	R	P	FR	
5		Polish each of the three segments	C	E	A	Cr	R	P	FR	
6		Record indication for difficulty or ease of working	C	E	A	R,Cr	R	-	FR	
7		Test the polished prototype segments	E,C	E	A	R,Cr	R	-	FR	
8		Measure surface figure with various temp.	E,C	E	A	R,Cr	R	-	FR	
9		Measure surface figure with various temp.	E,C	E	A	R,Cr	R	-	FR	
10		Deliver polished prototype segments	C	E	A	Cr	R	-	Delivery	
11		Executive summary	E,C	E	A	R,Cr	R	-	FR	
12		Detailed description of polishing process	C	E	A	P	R	-	FR	
13		Detailed description of acceptance testing process	E,C	E	A	R,Cr	R	-	FR	
14		Test data and resulting conclusion	E,C	E	A	R,Cr	R	-	FR	
15		Delivery	Delivery location of prototype and final report	E	-	-	R	-	-	Delivery
16			Relevant expenses	E	-	-	R	-	-	Delivery
17		Proprietary	Proprietary information	E	E	A	R	R	-	Occasionally
18	Basic information		E	E	A	R	R	-	Occasionally	
19	Releasing or publishing of the technical information		E	E	A	R	R	-	Occasionally	
20	Meetings	Review meeting (shall occur not later than 2wks prior to delivery)	E,C	E	A	R,Cr	R	-	RM	
21		Undecided contact by NOAO	A	A	E	-	-	R	Occasionally	
22	Surface	Figure error	C	E	A	Cr	R	-	FR	
23		Surface roughness	C	E	A	Cr	R	-	FR	
24		Surface imperfections	C	E	A	Cr	R	-	FR	
25		Minimize subsurface damage	C	E	A	Cr	R	-	FR	
26		Provide a structure function	C	E	A	Cr	R	P	FR	

Acronym	A	Approval	R	Responsibility	KOM	Kick-Off Meeting
	C	Control	Cr	Control	FR	Final Report
	E	Execution	P	Partial	RM	Review Meeting
	S	Support				

1. Overview - Development schedule



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1. Overview - Risk management

#	Risk and effectiveness	Prob.	Imp.	Mitigation plan	Consortium	Status (Due)
1	<input type="checkbox"/> Rick: Environmental testing <input checked="" type="checkbox"/> Not fully equipped facility in KASI	L	M	<input checked="" type="checkbox"/> Preparation of the facility - Find funding sources to purchase	KASI NOAO GO	Finish ('15.09)
	<input type="checkbox"/> Effectiveness <input checked="" type="checkbox"/> Not fully certified mirrors in operation condition			<input checked="" type="checkbox"/> Adjust testing plan - Mild temperature condition	NOAO KASI	Finish ('15.04)



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2. TECHNICAL VIEWPOINT

- POLISHING PROGRESS FOR COUPON

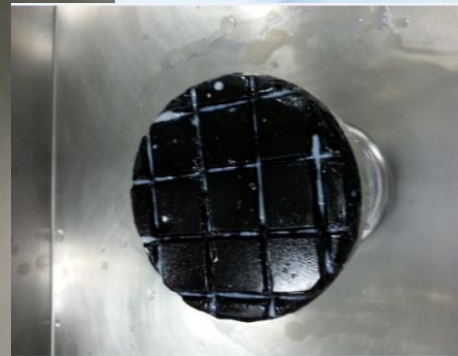
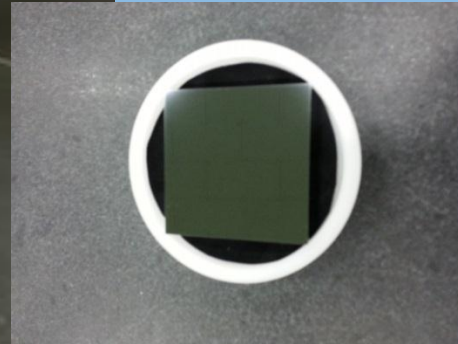
2. Polishing configuration for coupon

Slurry grain size

- 1st stage: 9, 1 μm
- 2nd stage: 6, 1 μm

Rotation speed

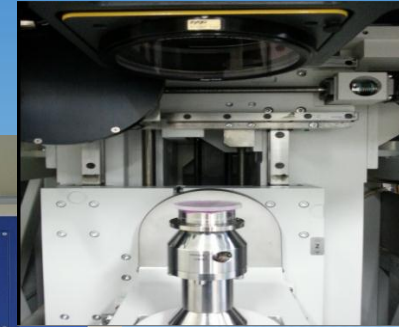
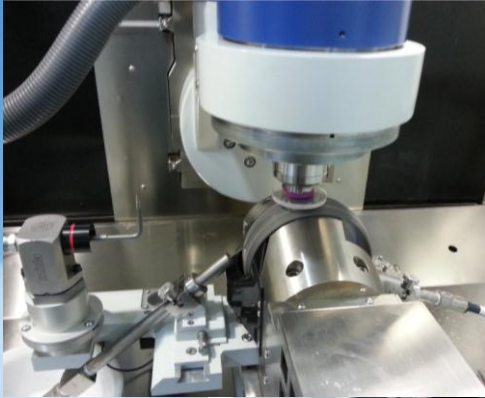
- Cam: 21 rpm
- Spindle: 64 rpm



Pitch polisher

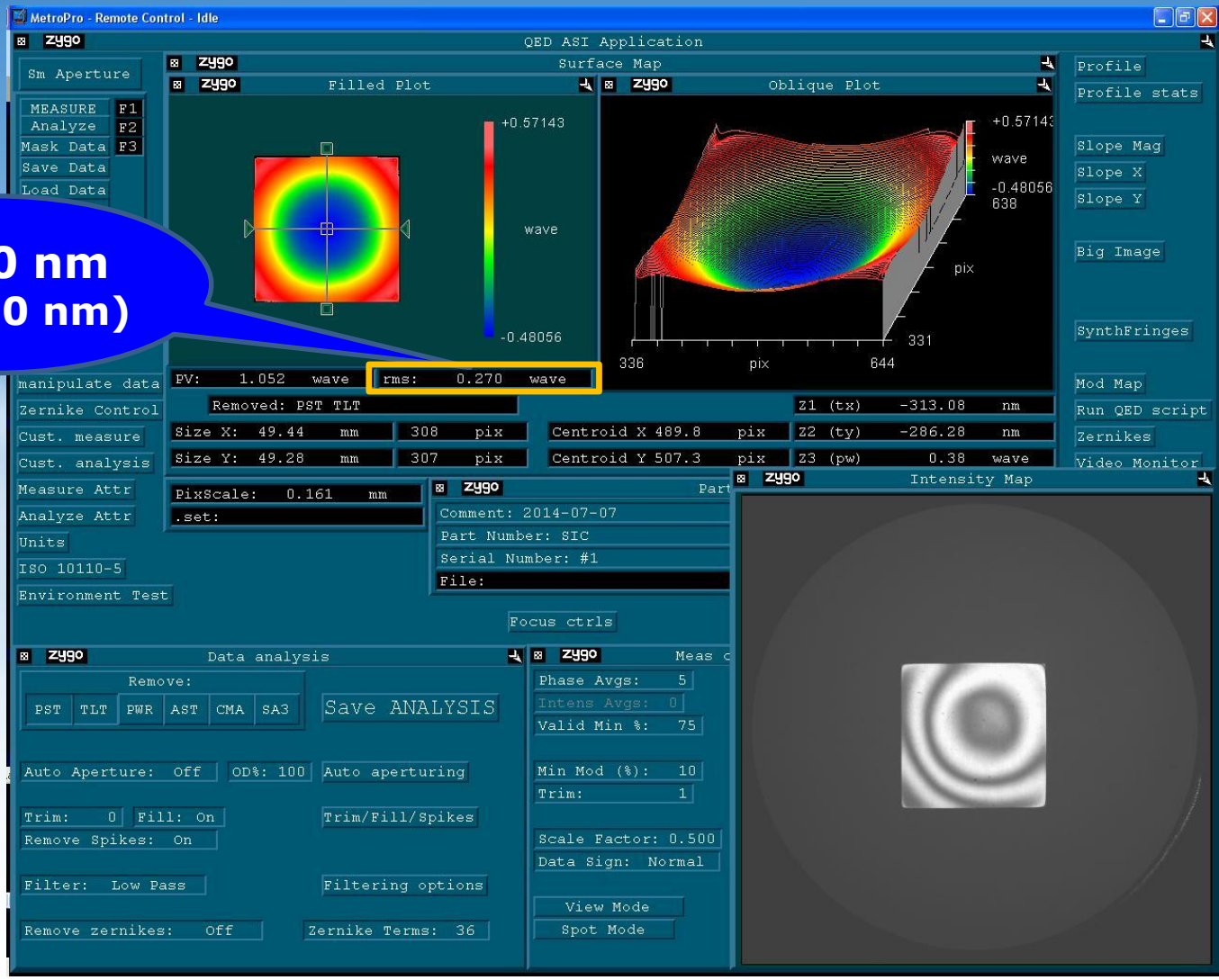
2. Polishing configuration for coupon

Finishing by
MRF and ASI



2. Figure error – before polishing of coupon

~ 170 nm
(req. 20 nm)



2. Figure error – Interim results (for 2 days)

~ 28 nm
(req. 20 nm)

The screenshot shows the Zygo MetroPro interface with the following data and settings:

- Surface Map:** A 2D color plot showing the surface profile. The color scale ranges from -0.10629 wave (blue) to +0.10632 wave (red).
- Oblique Plot:** A 3D surface plot showing the surface profile. The color scale ranges from -0.10629 wave (blue) to +0.10632 wave (red).
- Data Readouts:**
 - PV: 0.213 wave
 - rms: 0.045 wave (highlighted in a yellow box)
 - Z1 (tx): 110.22 nm
 - Z2 (ty): 150.40 nm
 - Z3 (pw): -0.39 wave
- Part Information:**
 - Comment: 2014-07-07
 - Part Number: SIC
 - Serial Number: #2
 - File:
- Data Analysis Settings:**
 - Remove: PST, TLT, PWR, AST, CMA, SA3
 - Save ANALYSIS
 - Auto Aperture: Off
 - OD%: 100
 - Auto aperturing
 - Trim: 0
 - Fill: On
 - Trim/Filter/Spikes
 - Remove Spikes: On
 - Filter: Low Pass
 - Filtering options
 - Remove zernikes: Off
 - Zernike Terms: 36
- Intensity Map:** A grayscale image showing the intensity distribution of the surface.

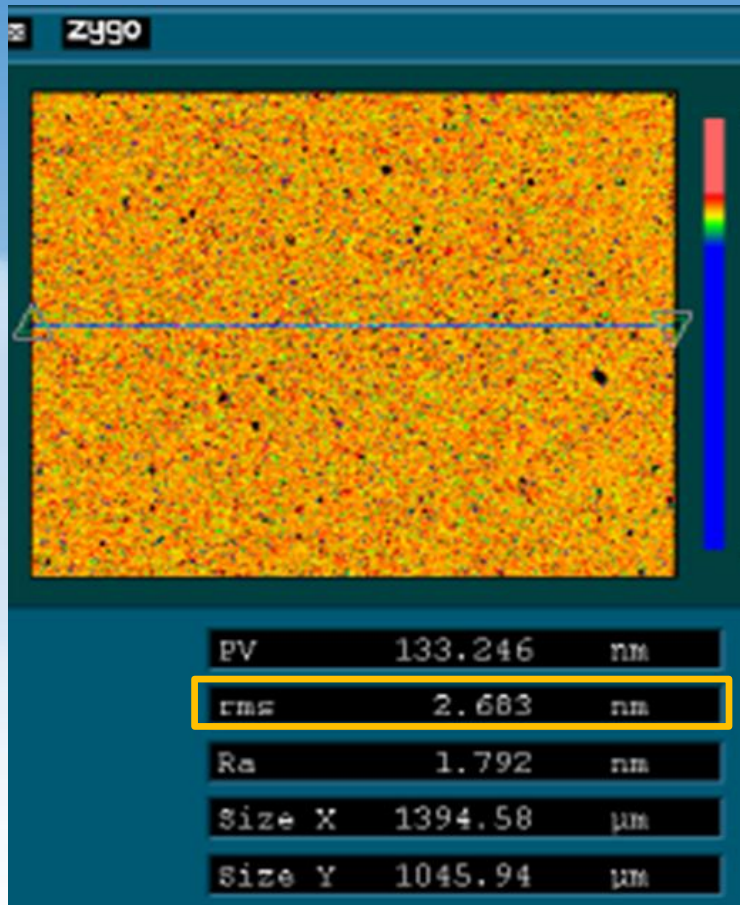
2. Figure error – meet requirement (Nov. 8, 2014)

12.3 nm
(req. 20 nm)

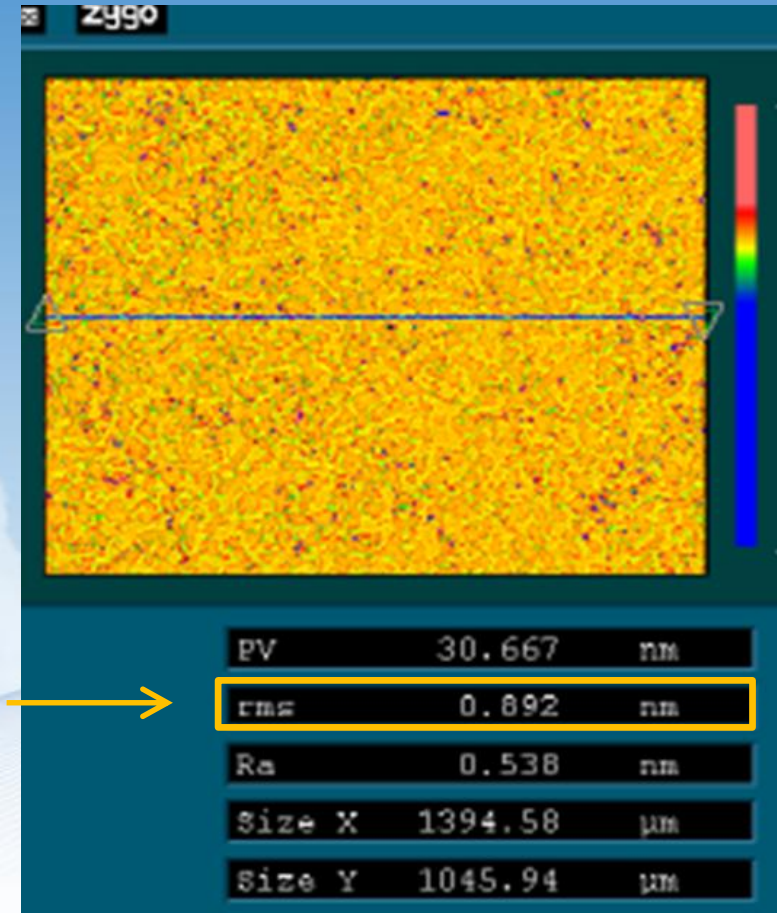
The screenshot displays the Zygo MetroPro software interface. The main window is titled 'MetroPro - Remote Control - Idle' and 'QED ASI Application'. It features several panels: 'Filled Plot' showing a 2D surface map with a color scale from -0.15309 to +0.03036 wave; 'Oblique Plot' showing a 3D surface map with a color scale from -0.15309 to +0.03036 wave; 'Data analysis' showing 'rms: 12.342 nm' highlighted in a yellow box; and 'Intensity Map' showing a grayscale image of the surface. The 'Data analysis' panel also shows 'Size X: 49.28 mm 307 pix', 'Size Y: 49.44 mm 308 pix', and 'Centroid X 476.9 pix', 'Centroid Y 493.0 pix'. The 'Intensity Map' panel shows 'Phase Avgs: 1', 'Intens Avgs: 0', 'Valid Min %: 75', 'Min Mod (%): 10', 'Trim: 1', 'Scale Factor: 0.500', and 'Data Sign: Normal'. The 'Focus ctrls' panel shows 'View Mode' and 'Spot Mode' buttons. The 'Environment Test' panel shows 'ISO 10110-5' and 'Environment Test' buttons. The 'Zernike Control' panel shows 'Removed: PST TLT' and 'Zernike Terms: 36'. The 'Part' panel shows 'Comment: 2014-11-07', 'Part Number: SiC PLANO', 'Serial Number:', and 'File:'.

2. Surface roughness

Req. = 2 nm rms



Slurry grain size: 9, 1 um



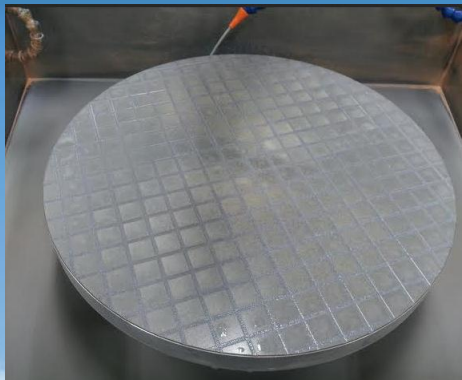
Slurry grain size: 6, 1 um

3. TECHNICAL VIEWPOINT

- POLISHING PROGRESS FOR $\Phi 300$

3. Polishing configuration for Φ 300 mm SiC

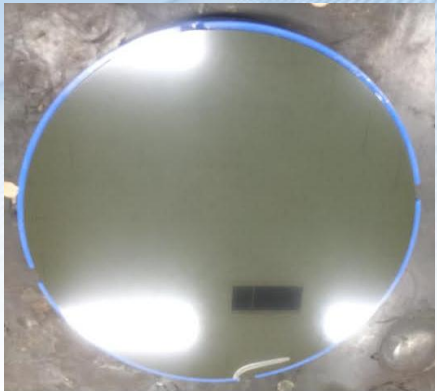
Slurry grain size
- 6, 1 μ m
Rotation speed
- Cam: 21 rpm
- Spindle: 64 rpm



Pad

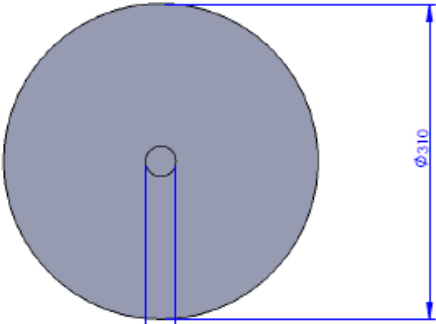
Polishing

Φ 300 SiC

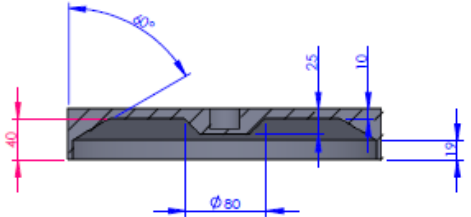
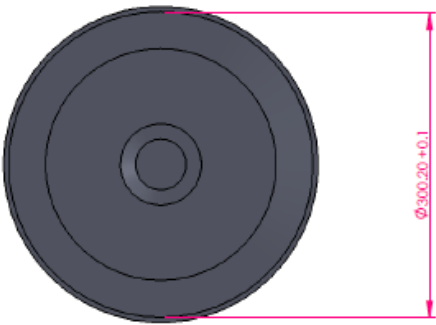
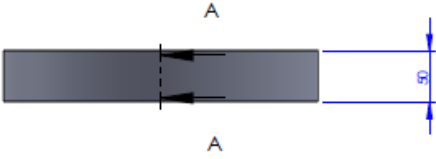


3. Polishing of Φ 300 mm SiC

Preparation of Jig



$\Phi 30 \nabla 20\text{mm}$



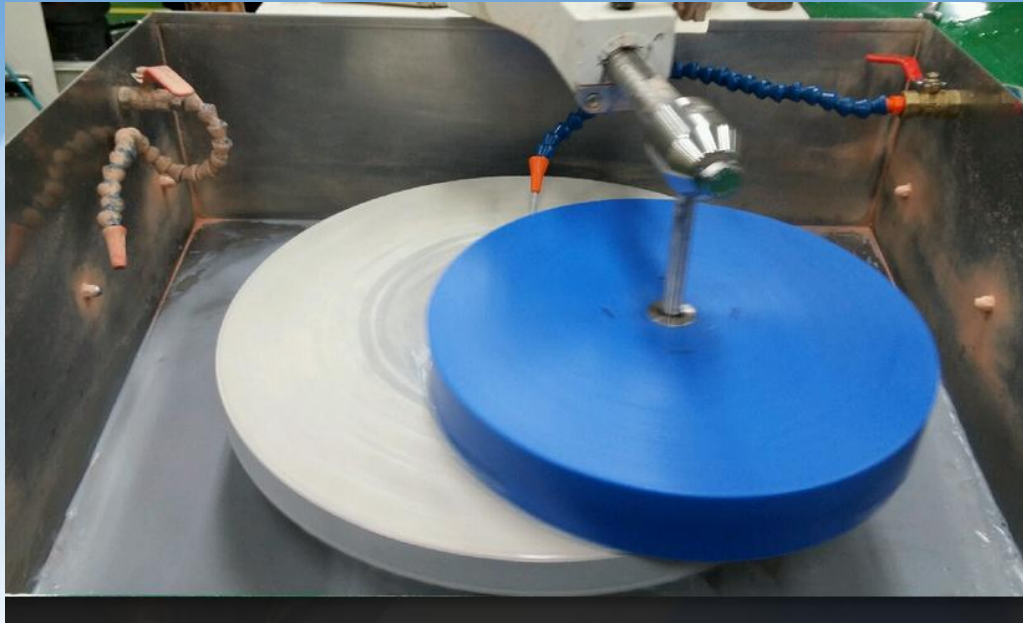
단면 A-A
확대 1:5

소재 : 아세탈 or MC
수량 : 1ea

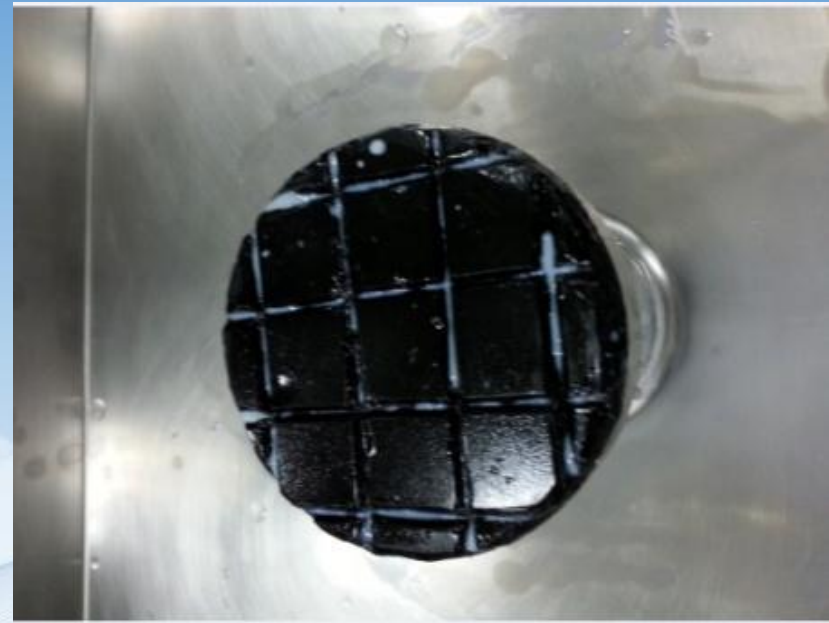


3. Polishing of Φ 300 mm SiC

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



SUBA pad



#73 pitch

3. Figure error – interim result (Nov. 14th)

~ 130 nm
(req. 20 nm)

The screenshot displays the Zygo MetroPro software interface. The main window is titled 'MetroPro - Remote Control - Idle' and 'QED ASI Application'. It features several panels: 'Filled Plot' (a 2D color map of a circular surface), 'Oblique Plot' (a 3D surface map), and 'Synthetic Fringe Map' (a grayscale fringe pattern of the same surface). The 'Filled Plot' shows a color scale from -1.18593 to +0.30338 wave. The 'Oblique Plot' shows a similar scale. The 'Synthetic Fringe Map' shows a circular fringe pattern. The 'Data analysis' panel at the bottom left shows 'Remove: PST TLT PWR AST CMA SA3' and 'Save ANALYSIS'. The 'Focus ctrls' panel shows 'Phase Avgs: 5', 'Intens Avgs: 0', 'Valid Min %: 75', 'Min Mod (%): 20', 'Trim: 1', 'Scale Factor: 0.500', and 'Data Sign: Normal'. The 'Profile' panel on the right shows 'Profile stats', 'Slope Mag', 'Slope X', 'Slope Y', 'Big Image', 'Intensity', 'Mod Map', 'Run QED script', 'Zernikes', and 'Video Monitor'. The 'Part/zygo' panel shows 'Comment: 2014-11-18', 'Part Number:', 'Serial Number:', and 'File: *****'. The 'Data analysis' panel shows 'Auto Aperture: Off', 'OD%: 100', 'Auto aperturing', 'Trim: 0', 'Fill: On', 'Trim/Fill/Spikes', 'Remove Spikes: On', 'Filter: Low Pass', 'Filtering options', 'Remove zernikes: Off', and 'Zernike Terms: 36'. The 'Focus ctrls' panel shows 'Z1 (tx): 3.48 nm', 'Z2 (ty): 0.51 nm', and 'Z3 (pw): -0.19 wave'. The 'Data analysis' panel shows 'PV: 1.489 wave', 'rms: 0.206 wave', 'Size X: 297.74 mm, 973 pix', 'Centroid X: 498.8 pix', 'Size Y: 298.04 mm, 974 pix', 'Centroid Y: 498.0 pix', 'PixScale: 0.306 mm', and 'Removed: PST TLT'. The 'Synthetic Fringe Map' panel shows 'Tilt Fringes: 4'.

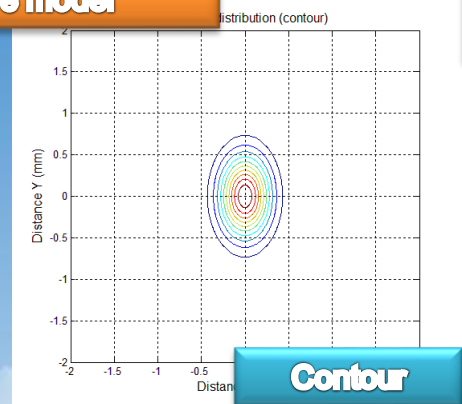
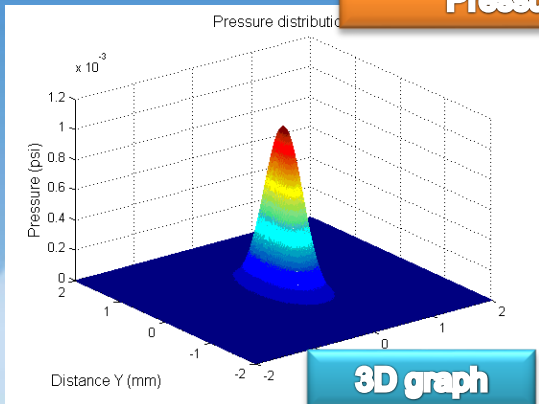
4. TECHNICAL VIEWPOINT

- TIF STUDY

4. TIF model development

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

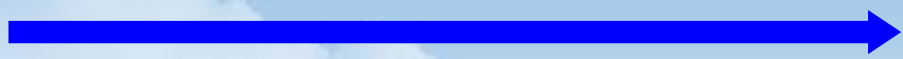
Pressure model



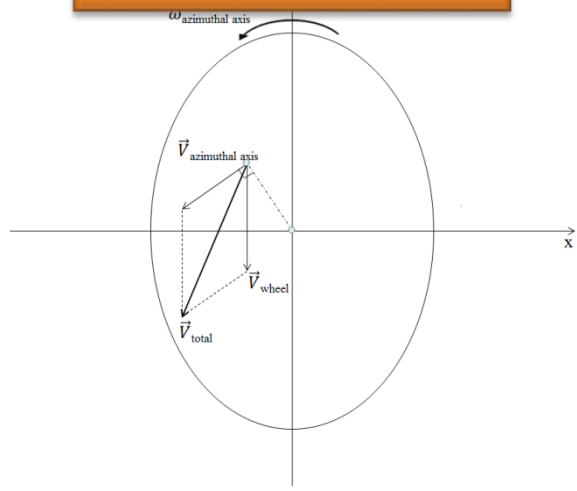
Corresponding Pressure Eq.

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

Wheel contact area



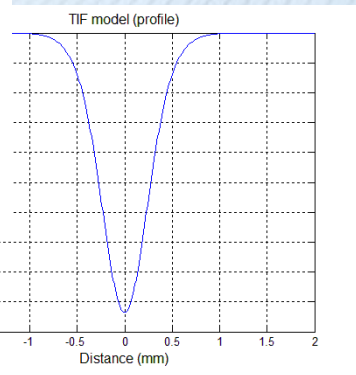
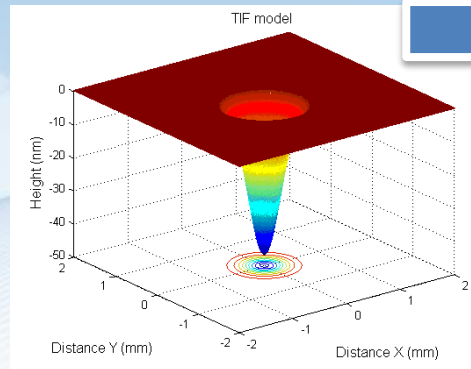
Definition of Velocities



Corresponding Preston Eq.

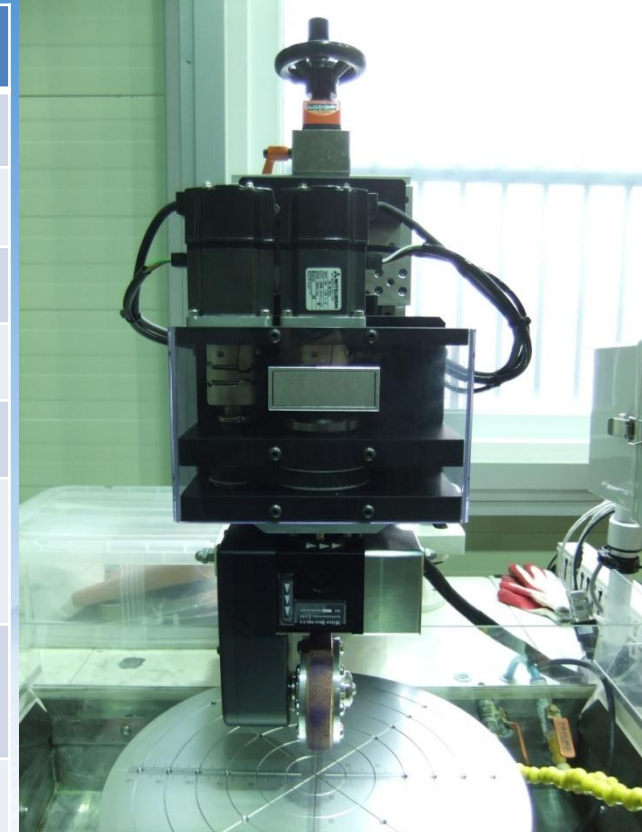
$$\Delta Z = \kappa \frac{e^{-\frac{1}{2}\left[\left(\frac{x}{\sigma_x}\right)^2 + \left(\frac{y}{\sigma_y}\right)^2\right]}}{2\pi\sigma_x\sigma_y} |\vec{V}_A + \vec{V}_W| \Delta t$$

TIF model



4. Polishing tool – requirement and specification

Items		Detailed items	Ranges / Spec.
Req.	TIF shape		Gaussian type
Spec.	Wheel	Rotation speed	15~1000 rpm
		Contact width	3.8 ~ 3.9 mm
		Contact area	6.0 ~ 6.5 mm ²
	Rotational axis (Radial direction)	Rotation speed	4~60 rpm
		Motion control item	Rotation angle Dwell time
Load cell	Measurement ranges	Min.: 0.1 psi Max.: 10 psi	
Development		KASI, SphereDyne, YoonSeul	



TIF polishing head

4. TIF generation on coupon

TIF generation

The screenshot displays the Zygo QED ASI Application interface. The main window is titled "Surface Map" and shows a 3D surface plot of a coupon with a grid of holes. A yellow circle highlights the grid area. The plot shows a color scale for wave height, ranging from -0.30157 to +0.12939. The plot is labeled "Zygo" and "Oblique Plot".

On the left side, there is a menu with options: MEASURE (F1), Analyze (F2), Mask Data (F3), Save Data, Load Data, Calibrate, and Reset. Below the menu, there are buttons for "manipulate data", "Zernike Control", "Cust. measure", "Cust. analysis", "Measure Attr", "Analyze Attr", "Units", "ISO 10110-5", and "Environment Test".

In the center, there are data fields: PV: 0.431 wave, rms: 0.052 wave. Below this, there are buttons for "Removed: PST TLT PWR". The size of the coupon is given as Size X: 49.44 mm (308 pix) and Size Y: 49.28 mm (307 pix). The centroid coordinates are Centroid X: 518.7 pix and Centroid Y: 449.9 pix. The PixScale is 0.161 mm. The file name is ".set:". The comment is "2014-11-07", Part Number is "#36", and Serial Number is blank.

On the right side, there are buttons for "Profile", "Profile stats", "Slope Mag", "Slope X", "Slope Y", "Big Image", "SynthFringes", "Mod Map", "Run QED script", "Zernikes", and "Video Monitor".

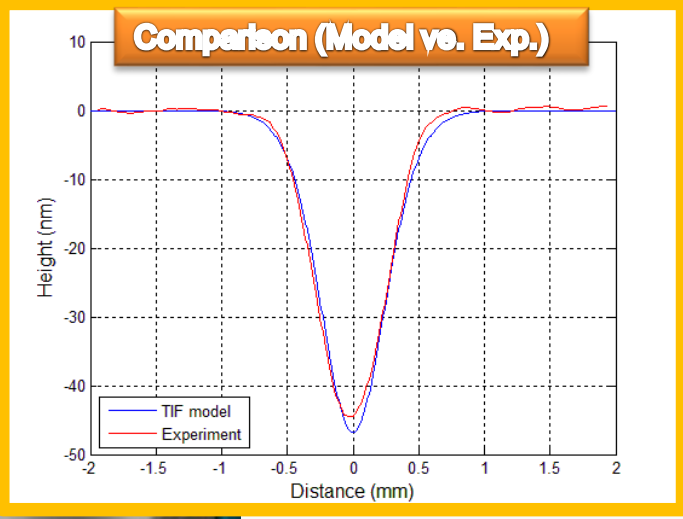
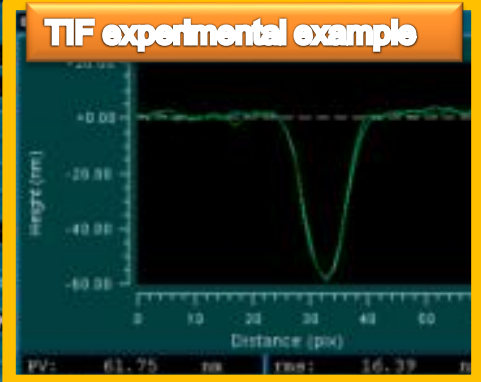
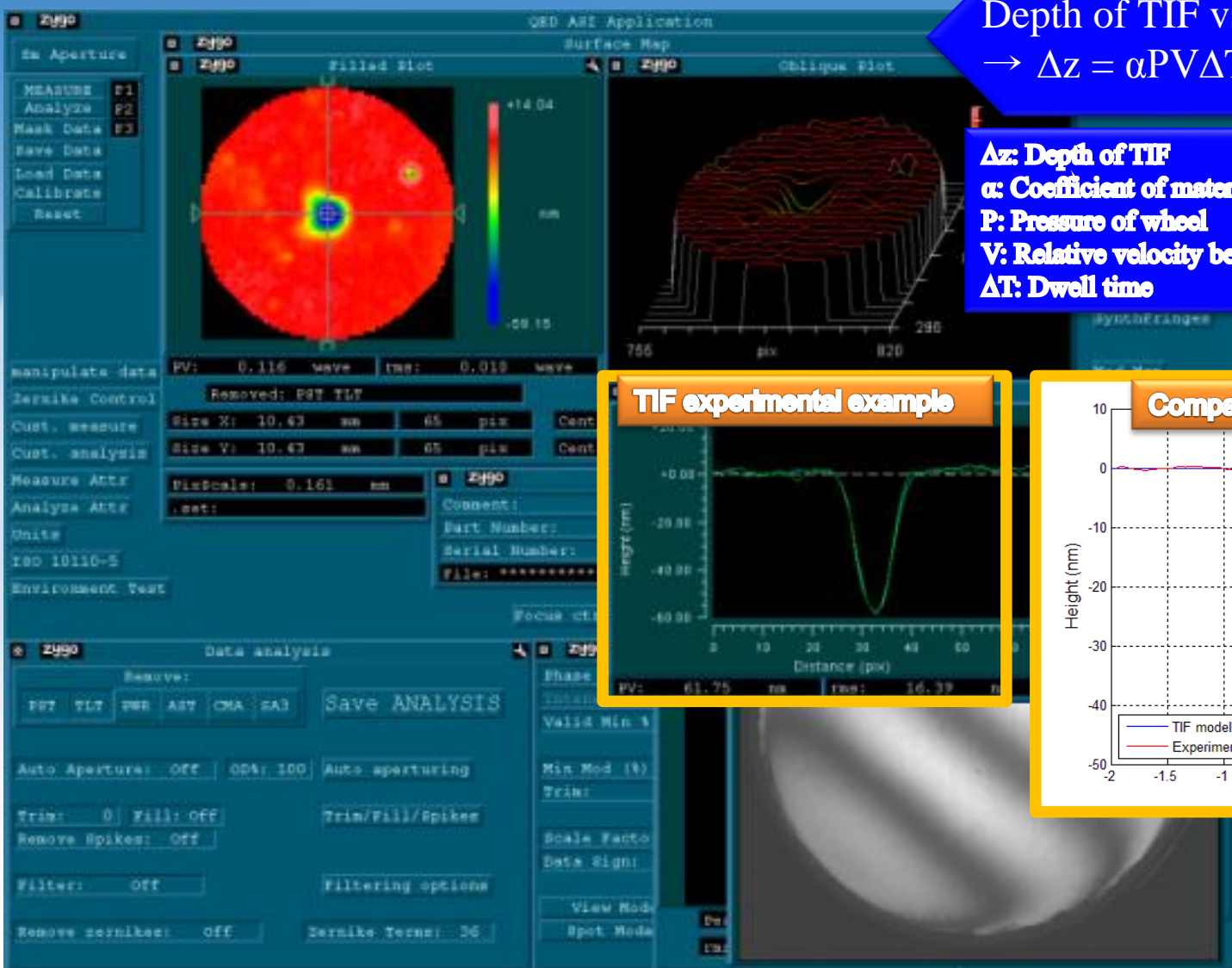
At the bottom, there is a "Data analysis" section with buttons for "Remove: PST TLT PWR AST CMA SA3" and "Save ANALYSIS". There are also buttons for "Auto Aperture: Off", "OD%: 100", "Auto aperturing", "Trim: 0", "Fill: Off", "Trim/Fill/Spikes", "Remove Spikes: Off", "Filter: Off", "Filtering options", "Remove zernikes: Off", and "Zernike Terms: 36".

On the bottom right, there is an "Intensity Map" section with buttons for "Phase Avgs: 1", "Intens Avgs: 0", "Valid Min %: 75", "Min Mod (%): 10", "Trim: 1", "Scale Factor: 0.500", "Data Sign: Normal", "View Mode", and "Spot Mode".

4. Preston equation and TIF comparison

Depth of TIF vs. Input variables
 $\rightarrow \Delta z = \alpha PV\Delta T$ (Preston Eq.)

Δz : Depth of TIF
 α : Coefficient of material removal
P: Pressure of wheel
V: Relative velocity between wheel and workpiece
 ΔT : Dwell time

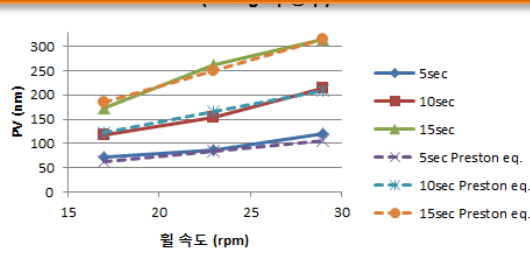
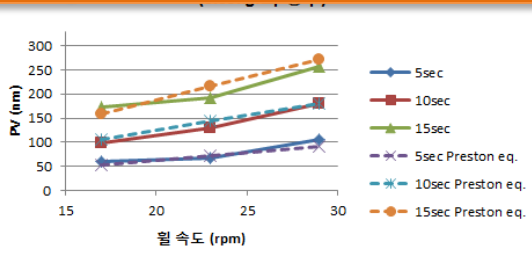
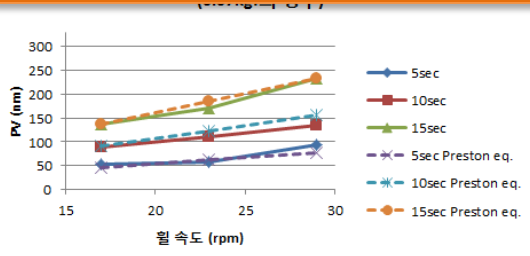


4. TIF analysis

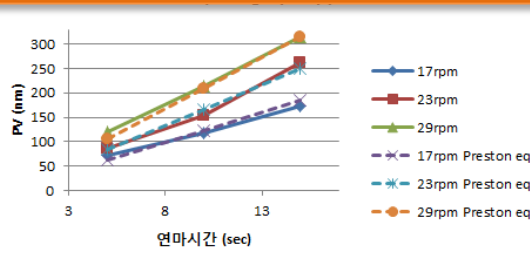
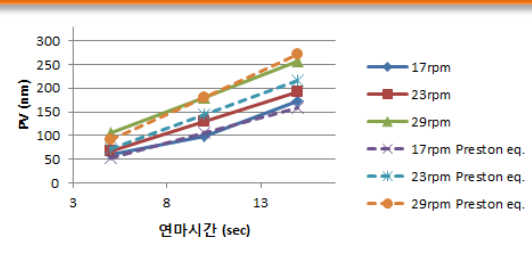
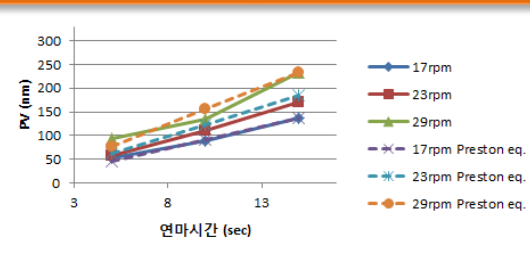
TIF analysis

Corresponding coef. of material removal (α) : 6.36 (um/(psi·hour·m/sec))

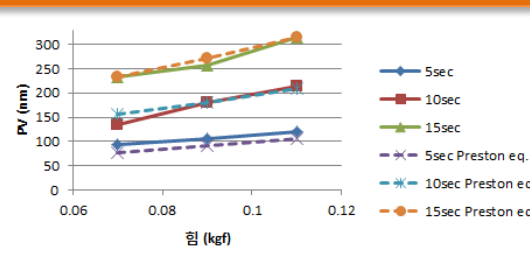
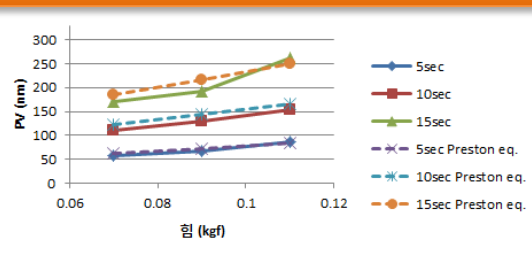
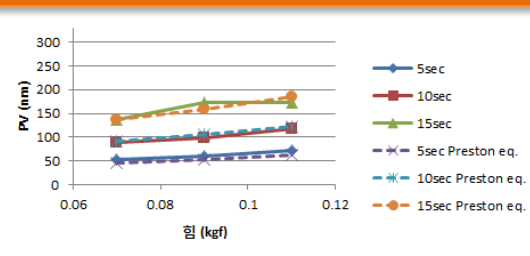
Az vs. V (Depth vs. Relative Velocity)



Az vs. Δ T (Depth vs. Dwell Time)



Az vs. P (Depth vs. Wheel Pressure)

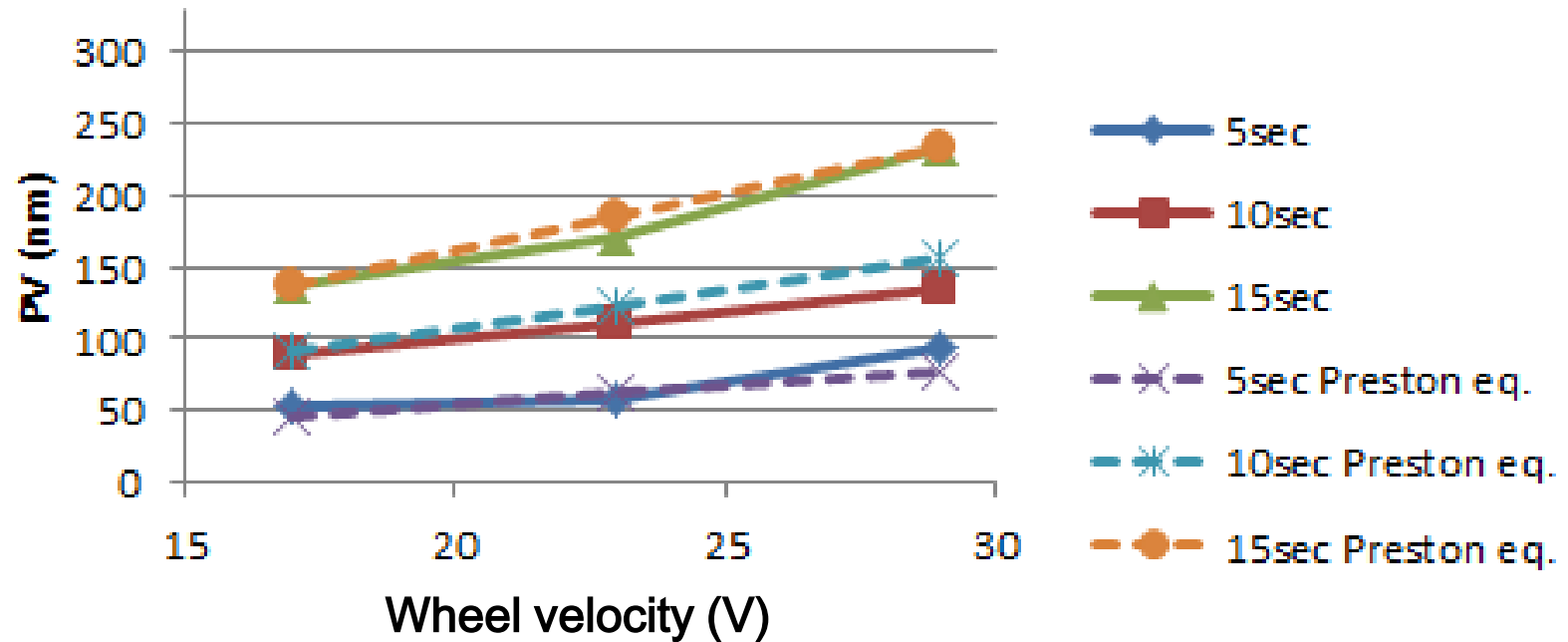


4. TIF analysis – in detail

TIF analysis

Δz vs. V (Depth vs. Relative Velocity)

PV vs. Wheel velocity (V)
(force at 0.07 kgf)

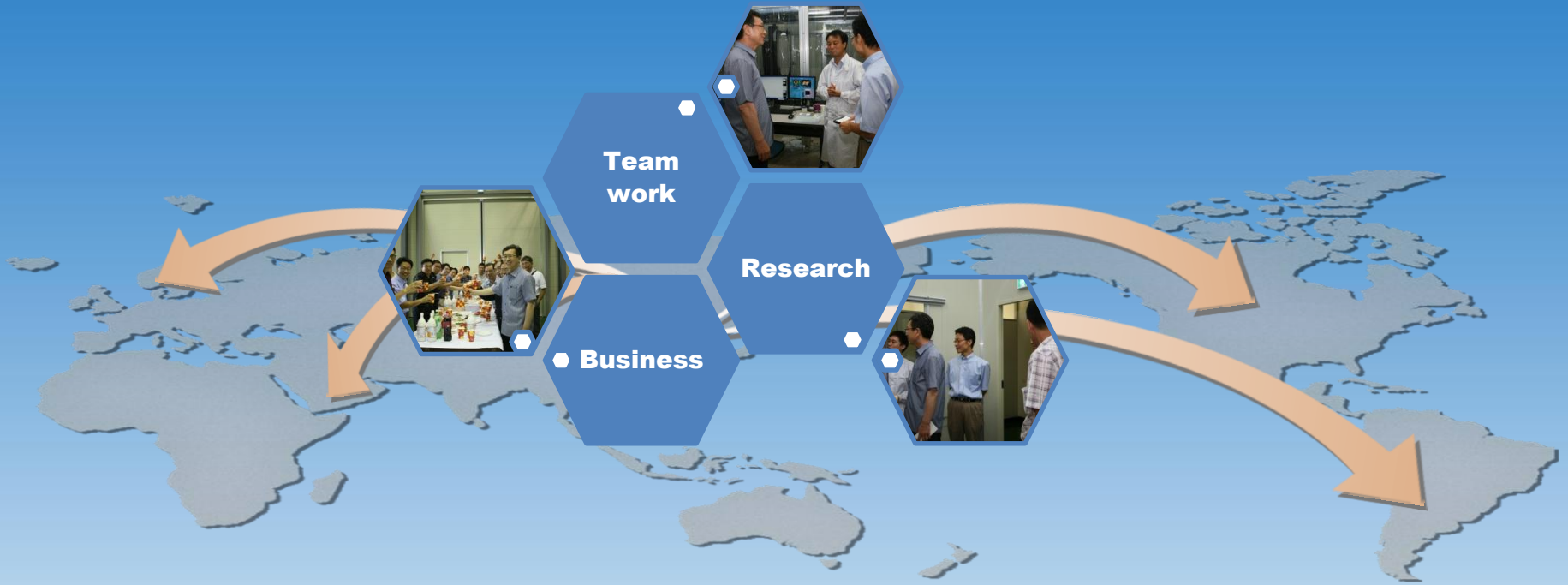


5. Results and Implication

- ❖ KASI-NOAO collaboration was established for core technology development of various SiC materials
- ❖ Successful results for SSGTM coupon from NOAO
 - Surface figure error: 12.3 nm rms (req. 20 nm rms)
 - Surface roughness: 0.9 nm rms (req. 2 nm rms)
- ❖ Works in progress for Φ 300 mm SiC from NOAO
 - Figure error: 130 nm rms (req. 20 nm rms)
 - Currently working on SSGTM and two more blanks in this year
- ❖ Present TIF patterns in progress
 - Well correspond with Preston Eq. → We plan to use the TIFs as a standard SiC TIF

6. Future SiC development plans

- ❖ KASI future plans for SiC development study
 - Preparation for next Phase SiC development
 - Size: lightweight 500 mm SiC mirrors
 - Shapes: Off-axis, Convex and Concave aspheric
 - Scope: Development of material process, polishing, metrology
 - Period: 2016~2018 (3 years)
- ❖ KASI plan to collaborate with vendors and universities
 - Material: SKC solmics, Orange E&C, Wonik Q&C, Dandan, University of Seoul
 - Polishing: GO, KBSI, Yonsei University
- ❖ Continue to study TIF: Generate and analyze TIFs
 - Build up a TIF map for various SiC materials
 - Could be provided a valuable TIF information for SiC



Thank you for your attention