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Accelerating Process Optimization and Consumable Development for CMP with a Benchtop Platform

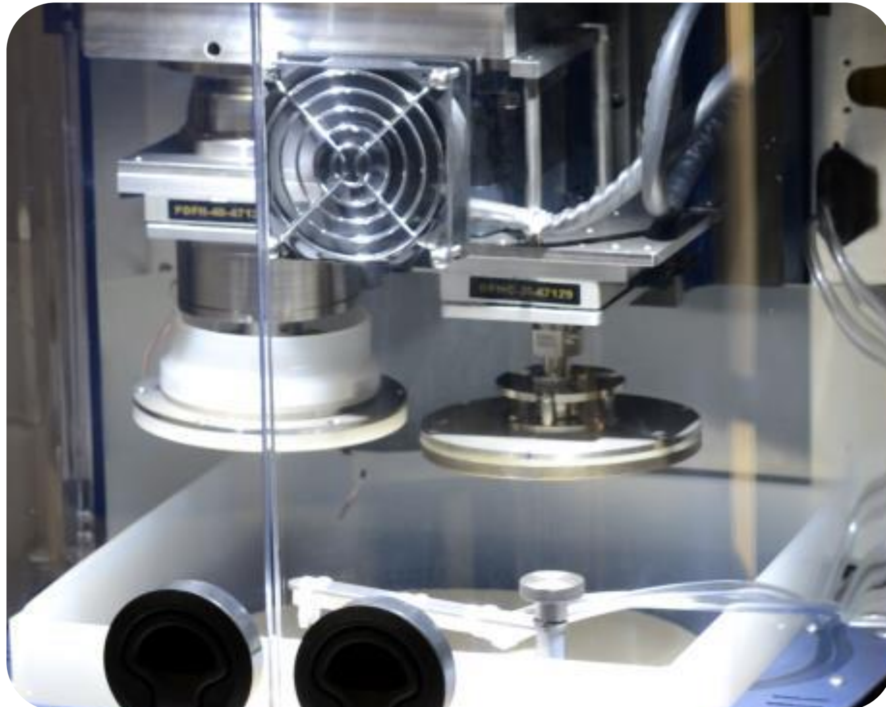
Peter De Wolf & Damien Khoo , Bruker Nano Surfaces & Metrology

November 11, 2022

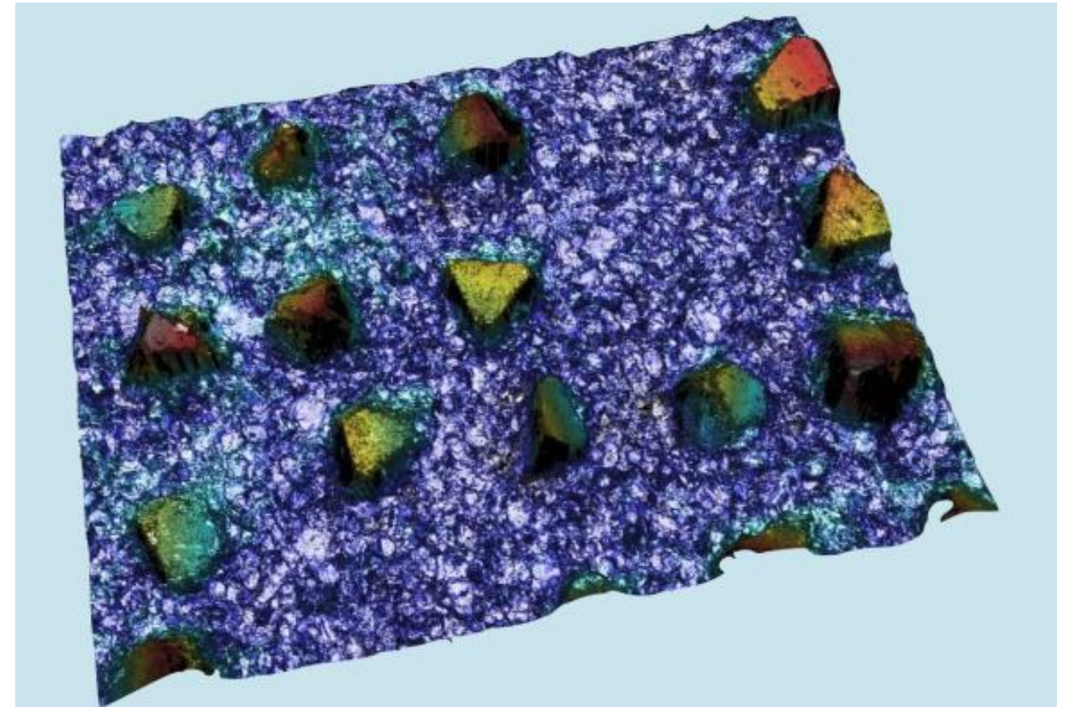
@ CMP & Wet User Meeting - Amsterdam

Outline

- **Benchtop system applied to reproduce, simulate & optimize various CMP processes**



- **Characterization using Optical Profiling & Atomic Force Microscopy**



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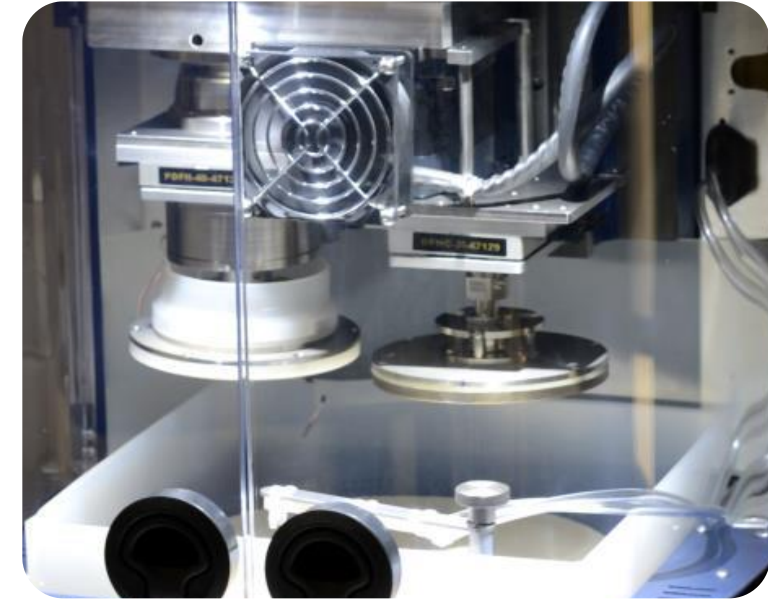
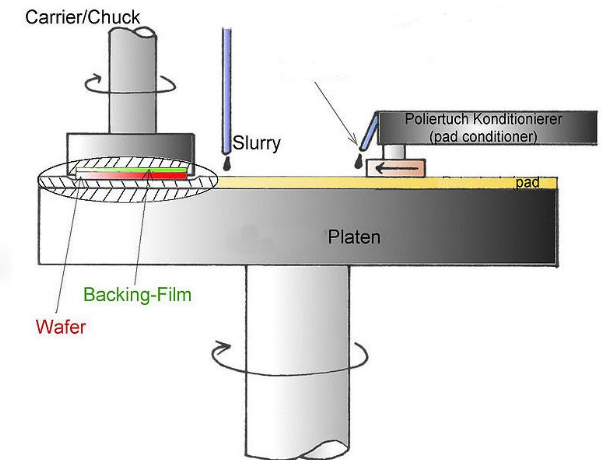
Benchtop CMP System Concept

- Small footprint R&D setup
- Reproduces full-scale wafer polishing process conditions and consumables
- Capable of performing tests on wafers (upto 4 inch) and small coupons





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Benchtop CMP System

Motorized lateral positioning stage
Lateral range 75 mm and 0.25 µm (encoded) resolution
Vertical range 100 mm, and 0.5 µm (encoded) resolution

Head Rotation & Pressurizing mechanism (up to 500 rpm, up to 400 N)

Wafer (upto 4 inch) / Coupon
(mounted upside down on carrier)

Pad Conditioner (upto 200 N, 4.25 inch)

Slurry / Water Nozzles with programmable pumps

9 inch Polishing Pad holder
Rotational drive provides torque and speed (2.5 Nm @ 500 rpm).

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Test Program / Recipe

CMP-Recipe.cts
- Condition
  - 1) Apply Load
  - 2) Condition + water flow
- Polish
  - 1) Apply load
  - 2) Polish + Slurry flow
  - 3) Polish + Water flow
- Polish + Condition
  - 1) Apply load
  - 2) Polish + Slurry flow
  - 3) Polish + Water flow
- Rinse
  - 1) Pad rotation + Water flow

CP4 Test

Duration: 60 ◉ Seconds ○ Minutes ○ Hours

Wafer Shape and Size: 50 mm Inner Diameter 0 mm Outer Diameter 0 mm

Control by:
◉ Wafer ○ Conditioner ○ Carriage Position
○ Pressure ◉ Force -22.2 lb
Offset: 0 mm ◉ Up ○ Down
Speed: 0 mm/sec

Pad: 200 RPM ☐ Move Immediately
Direction: ◉ Clockwise ○ CounterClockwise

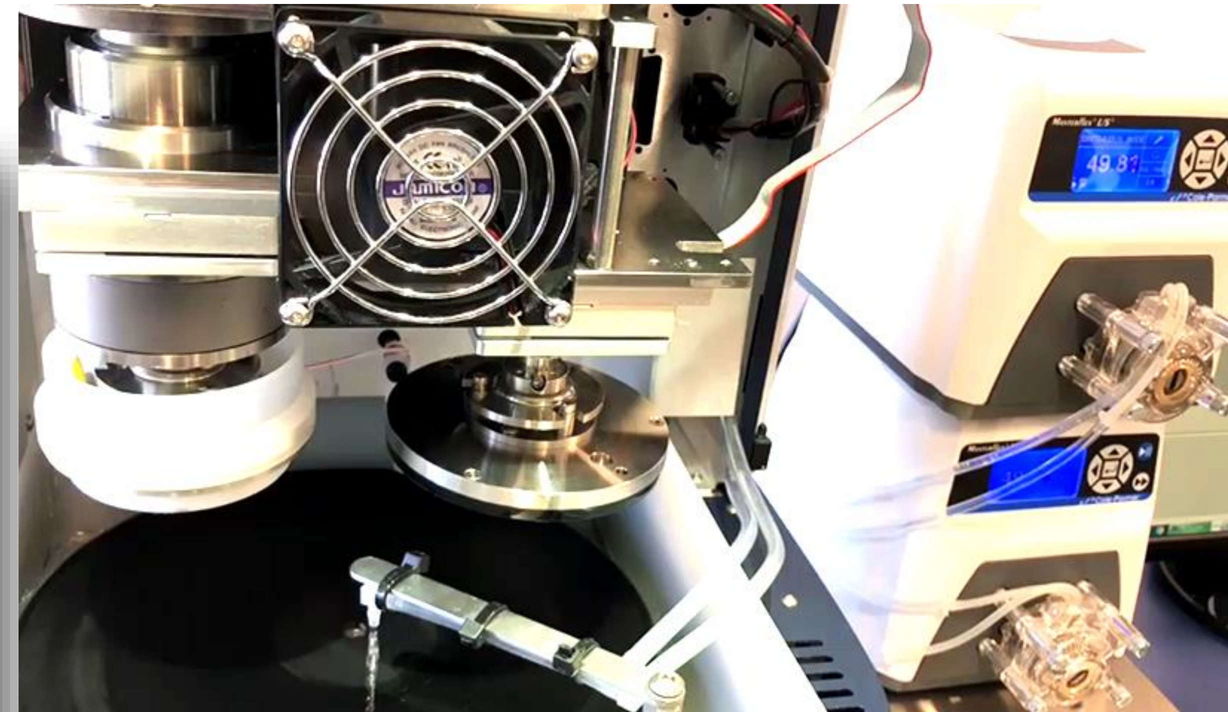
Wafer: 350 RPM ☐ Move Immediately
Direction: ○ Clockwise ◉ CounterClockwise

Slider: ☑ From: 55 To: 65 Cycles per min: 10

Pumps
☐ Use Pump 1 Flow Level: 50 mL/min
☑ Use Pump 2 Flow Level: 100 mL/min

Power Supply
◉ Not Used ○ Set Voltage ○ Set Current 0 V

☑ Save Data at every 1 th loop



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Test Program / Recipe

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- Condition
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  - 2) Polish + Slurry flow
  - 3) Polish + Water flow
- Rinse
  - 1) Pad rotation + Water flow

CP4 Test

Duration: 60 Seconds / Minutes / Hours

Wafer Shape and Size: 50 mm Inner Diameter 0 mm Outer Diameter 0 mm

Control by: Wafer / Conditioner / Pressure / Force -22.2 lb / Carriage Position

Offset: 0 mm Up / Down

Speed: 0 mm/sec

Pad: 200 RPM, Move Immediately; Direction: Clockwise / CounterClockwise

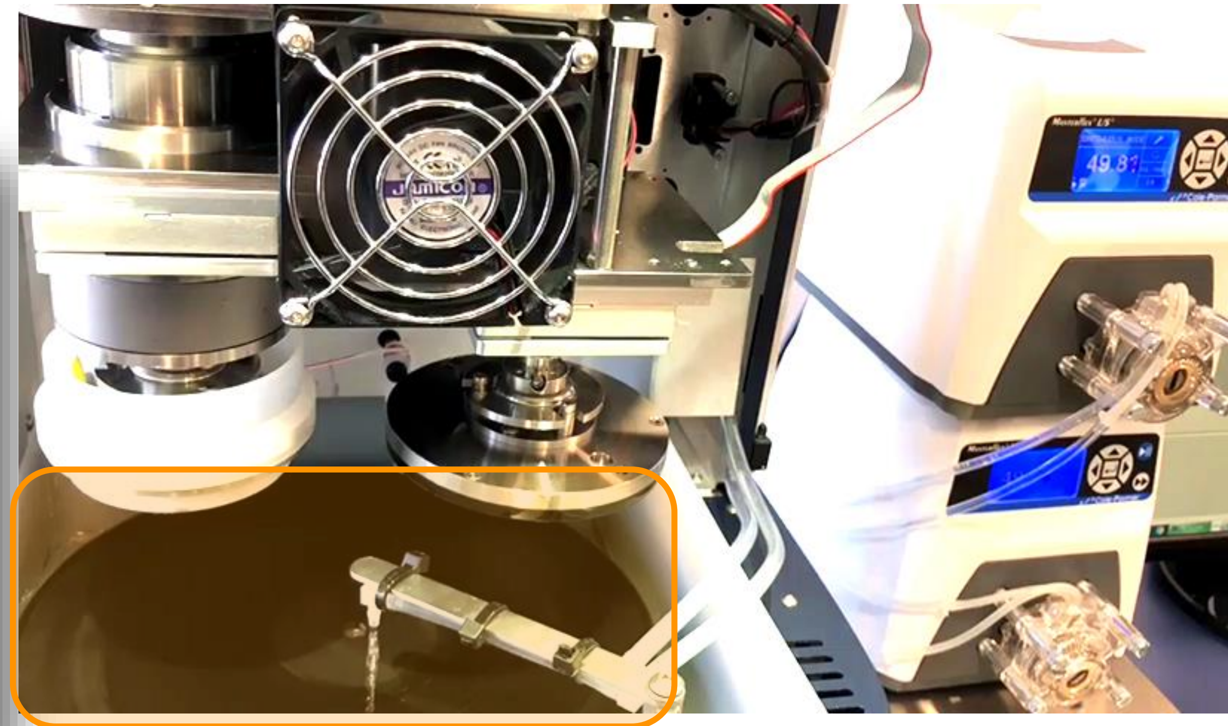
Wafer: 350 RPM, Move Immediately; Direction: Clockwise / CounterClockwise

Slider: From: 55 To: 65 Cycles per min: 10

Pumps: Use Pump 1 Flow Level: 50 mL/min; Use Pump 2 Flow Level: 100 mL/min

Power Supply: Not Used / Set Voltage / Set Current 0 V

Save Data at every 1 th loop



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Test Program / Recipe

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- Condition
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  - 1) Pad rotation + Water flow

CP4 Test

Duration: 60 — Seconds / Minutes / Hours

Wafer Shape and Size: 50 mm — Inner Diameter 0 mm — Outer Diameter 0 mm

Control by: Wafer / Conditioner / Carriage Position — Pressure / Force: -22.2 lb

Offset: 0 mm — Up / Down
Speed: 0 mm/sec

Pad: 200 RPM — Move Immediately — Direction: Clockwise / CounterClockwise

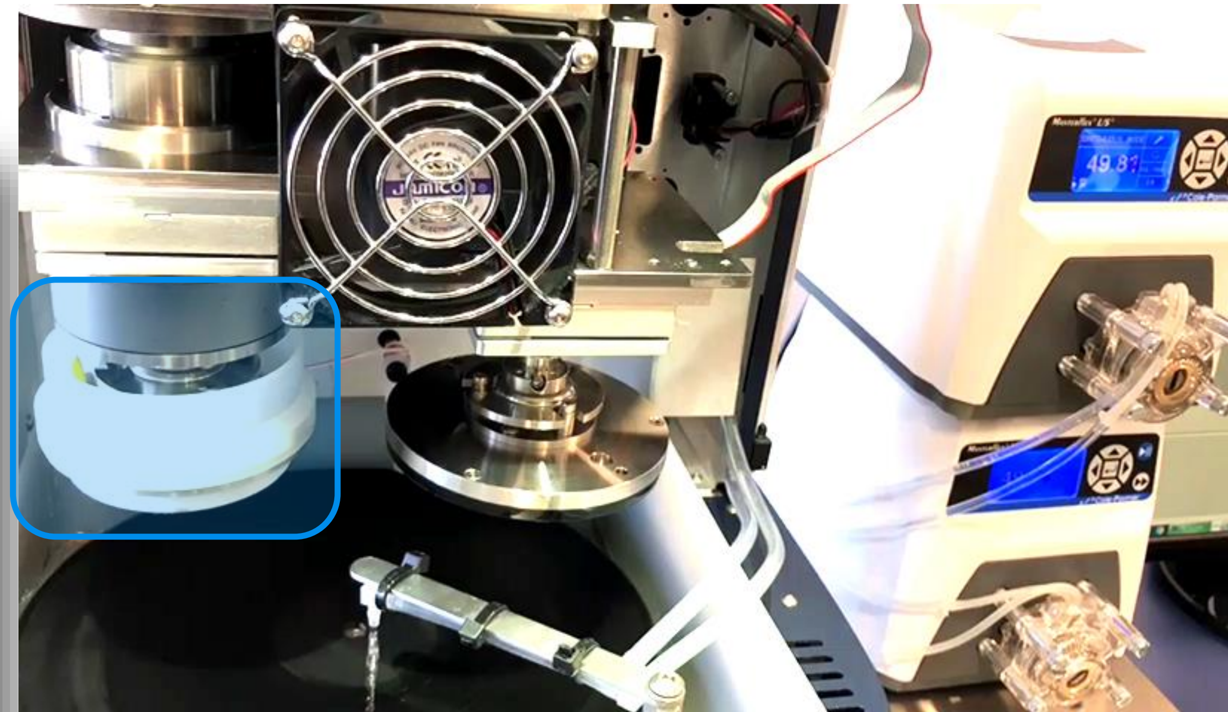
Wafer: 350 RPM — Move Immediately — Direction: Clockwise / CounterClockwise

Slider: From: 55 To: 65 — Cycles per min: 10

Pumps: Use Pump 1 — Flow Level: 50 mL/min; Use Pump 2 — Flow Level: 100 mL/min

Power Supply: Not Used / Set Voltage / Set Current — 0 V

Save Data at every 1 th loop



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Test Program / Recipe

CMP-Recipe.cts

- Condition
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CP4 Test

Duration: 60 — (•) Seconds ( ) Minutes ( ) Hours

Wafer Shape and Size: 50 mm — Inner Diameter 0 mm — Outer Diameter 0 mm

Control by: (•) Wafer ( ) Conditioner ( ) Pressure (•) Force -22.2 lb ( ) Carriage Position

Offset: 0 mm ( ) Up ( ) Down

Speed: 0 mm/sec

Pad: 200 RPM — [ ] Move Immediately — Direction: (•) Clockwise ( ) CounterClockwise

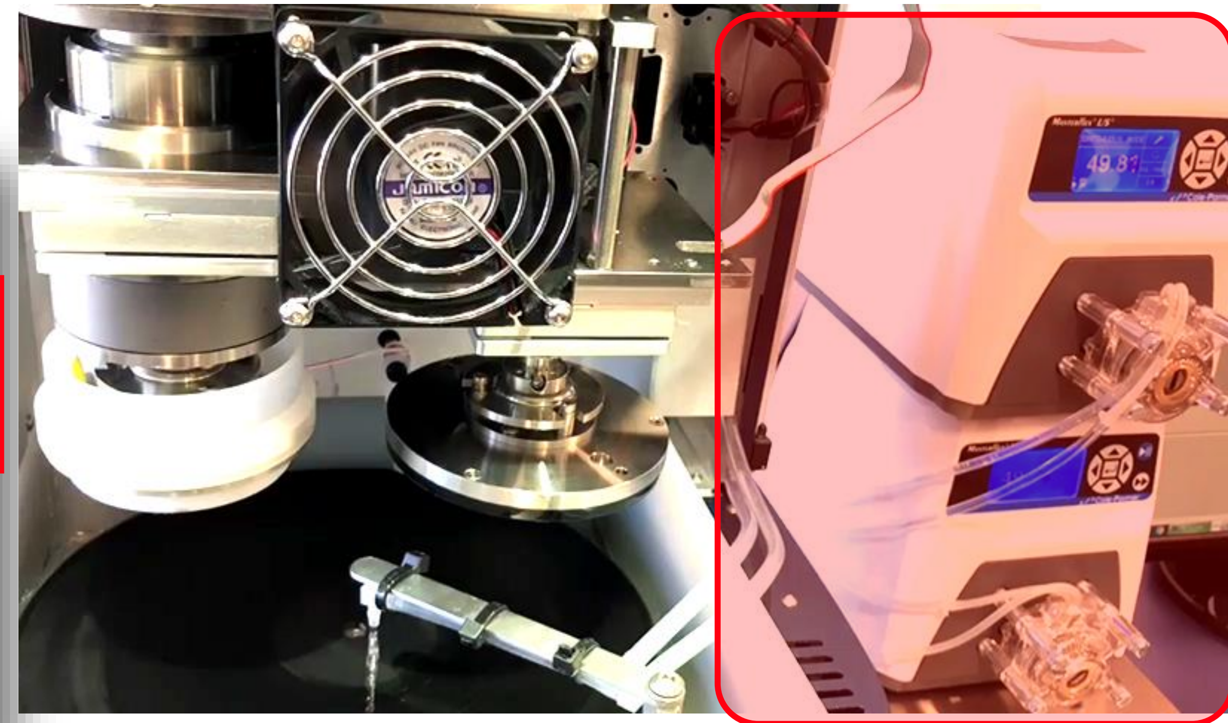
Wafer: 350 RPM — [ ] Move Immediately — Direction: ( ) Clockwise (•) CounterClockwise

Slider: [x] From: 55 To: 65 — Cycles per min: 10

Pumps: [ ] Use Pump 1 — Flow Level: 50 mL/min; [x] Use Pump 2 — Flow Level: 100 mL/min

Power Supply: ( ) Not Used ( ) Set Voltage ( ) Set Current 0 V

[x] Save Data at every 1 th loop



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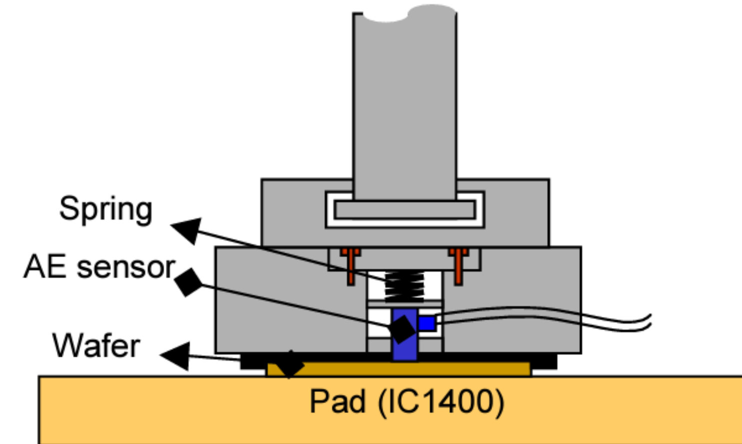
In-situ Monitoring

- Properties measured:
  - Coefficient of Friction
  - Acoustic Emission (in wafer chuck)
  - Temperature
  - Pad wear
  - Electrical surface resistance
  - ..



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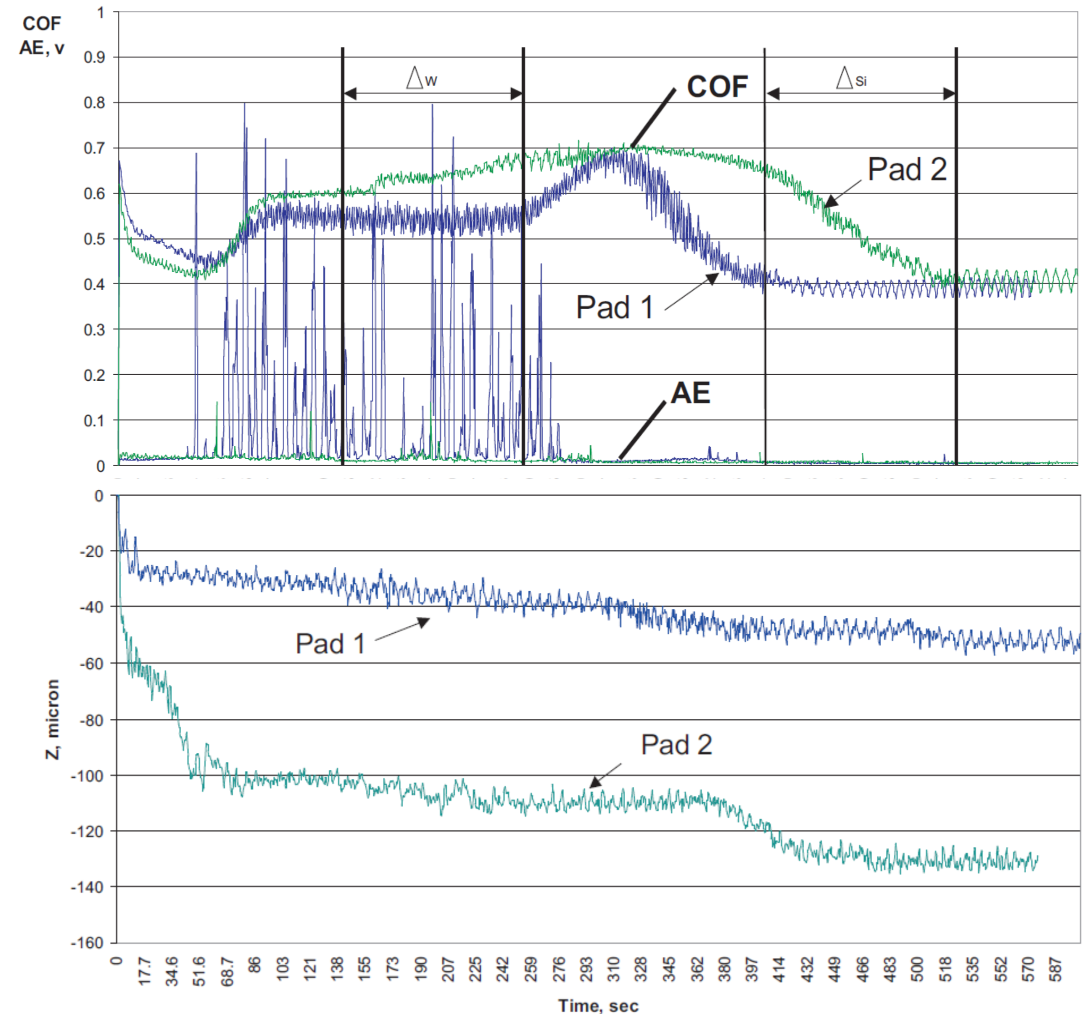
Effect of Pads

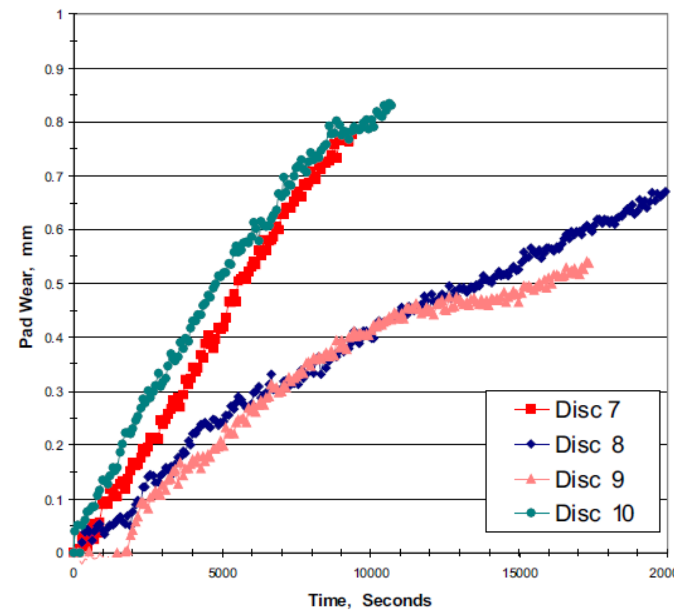
- Test example: 10 min. test on Si wafer with ILD & W layers (2 different pads)

- Results:
  - Both transition zones (from W to ILD and from ILD to Si) were shorter for pad 1 than for pad 2. Pad 1 produces less non-uniformity / mixing.
  - Both W and IL are removed faster by pad 1
  - Wear of pad 1 (50 μm) was much smaller than wear of pad 2 (130 μm)

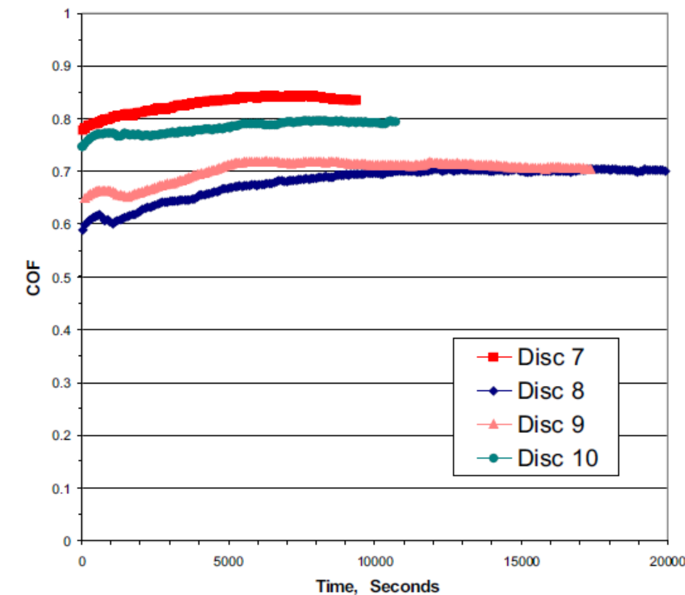


Effect of Conditioning Discs on Pad Wear

- Test example:
  - 4 different conditioning disc types (Abrasive Technology). 90 rpm & 15 mm @ 5 mm/s lateral.
  - 6 inch Pad made by Rodel. 100 rpm
  - Normal load 30 N



Pad Wear comparison identifies two disc groups (2.6x higher)



Friction coefficient (COF) correlates with Pad Wear: larger COF results in higher wear rate.

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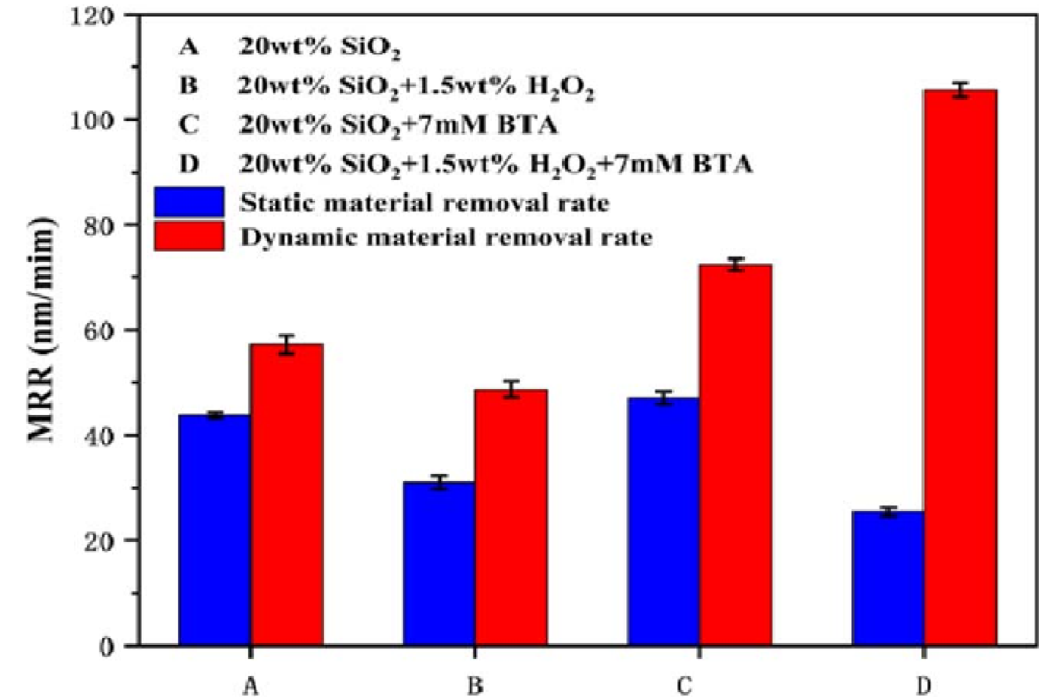
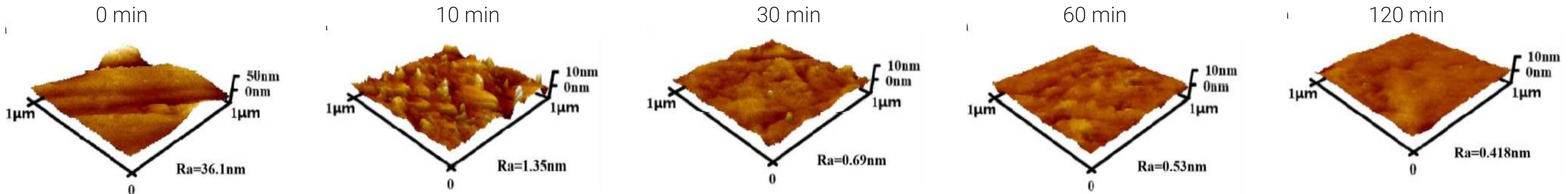
Effect of Slurry in ElectroChemical Mechanical Polishing (ECMP)

- ECMP integrates the actions of electric corrosion, chemical corrosion and mechanical removal. Can acquire a high MRR under a small down pressure.

- Ref. Xie, F., et al., ECS Journal of Solid State Science and Technology, 10(10), 104004. (2021)
  - Sample: Cobalt surface
  - Roughness 1.35 nm after 10 min, 0.418 nm after 120 min





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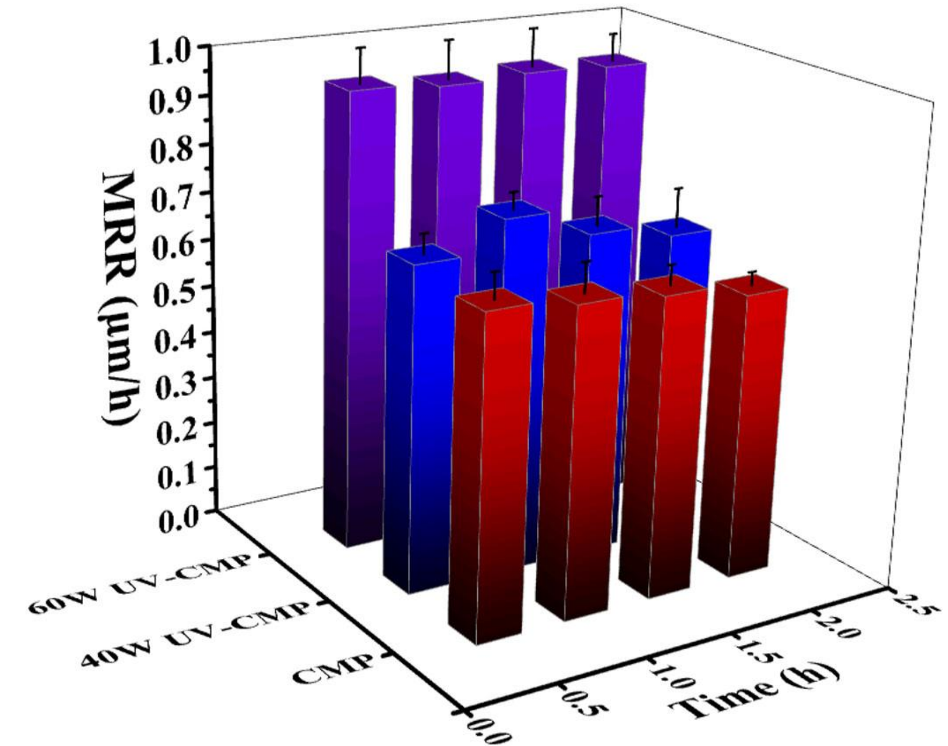
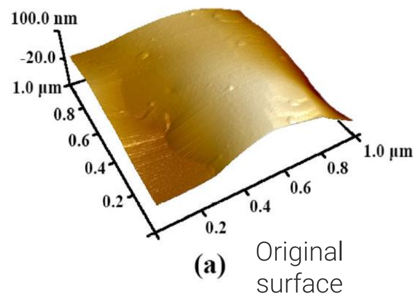
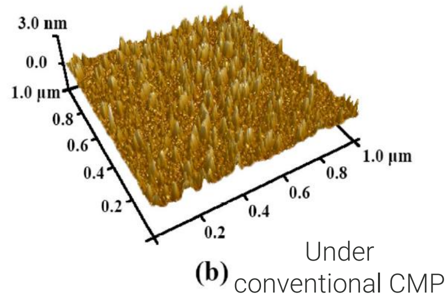
Ultrasonic Vibration Assisted CMP (UV-CMP)

- Test goal: Measure polishing efficiency improvements (surface quality & MRR) on chemically inert and high hardness materials.
- Ref. Zhou, M., et al. *Mechanics of Advanced Materials and Structures*, 1-18 (2021).
  - Sample: sapphire.

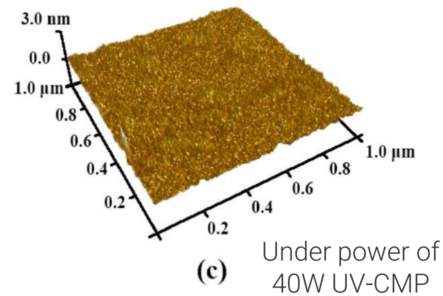




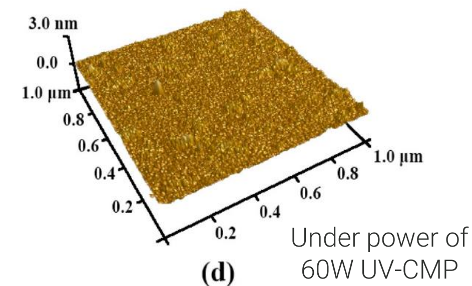
Original surface



Under conventional CMP



Under power of 40W UV-CMP



Under power of 60W UV-CMP

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Outline

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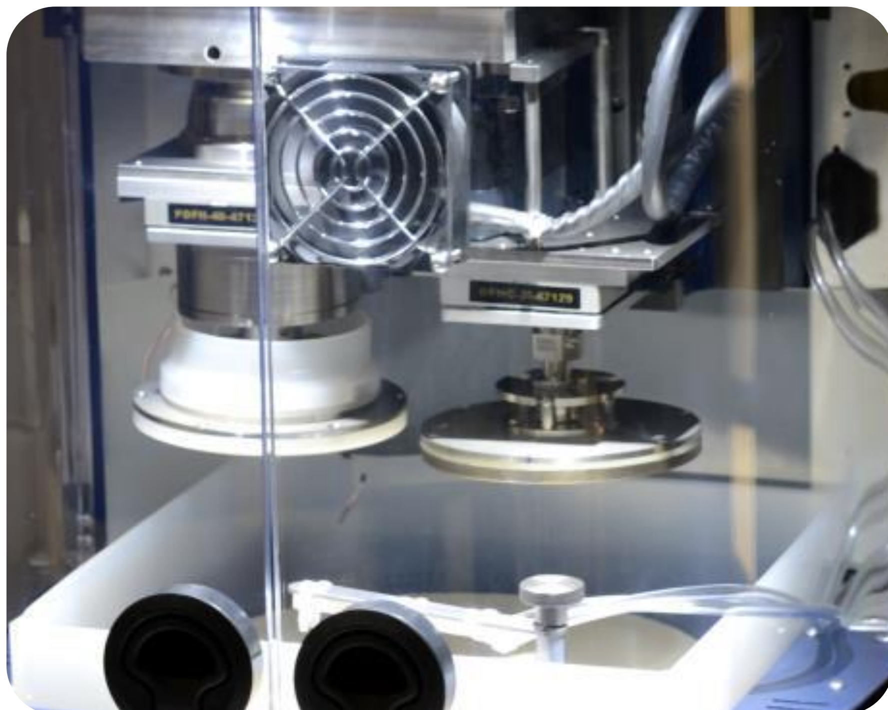
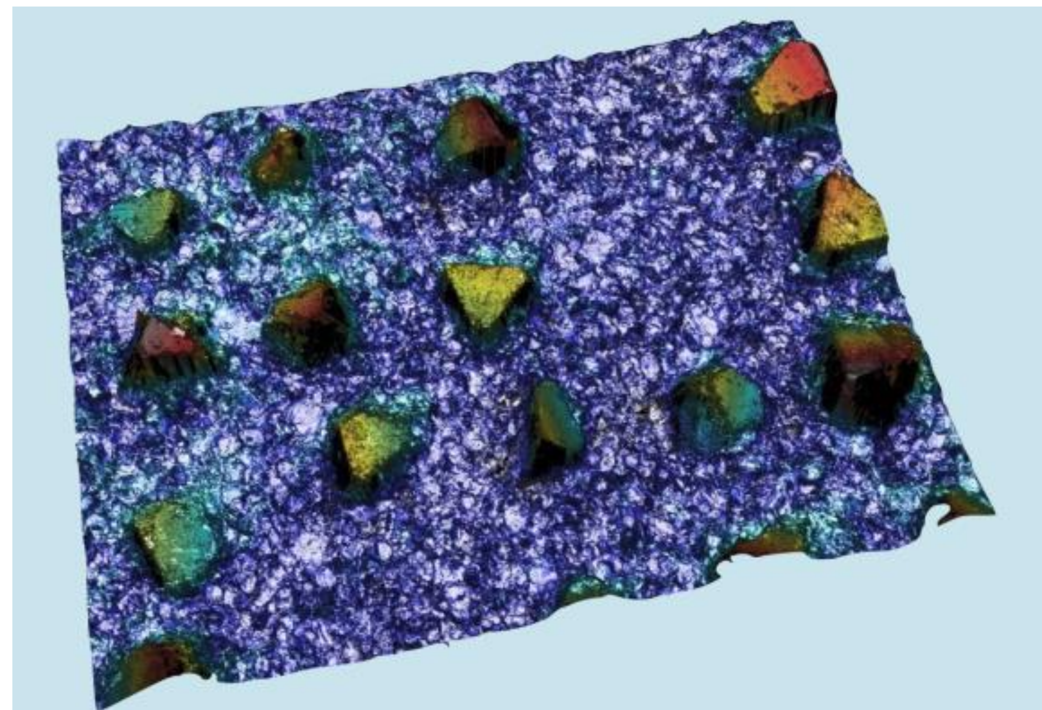
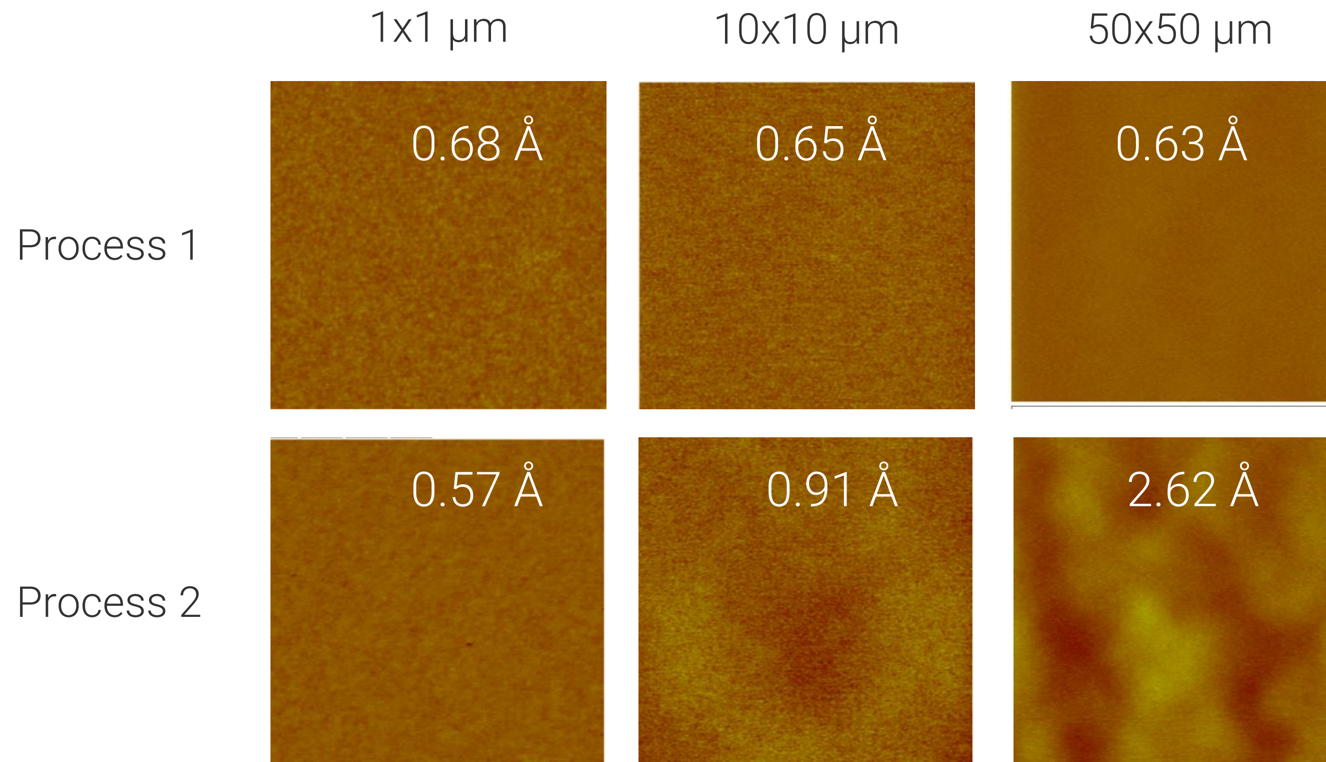


- **Characterization using Optical Profiling & Atomic Force Microscopy**



AFM for High-Resolution Imaging: Roughness, Waviness



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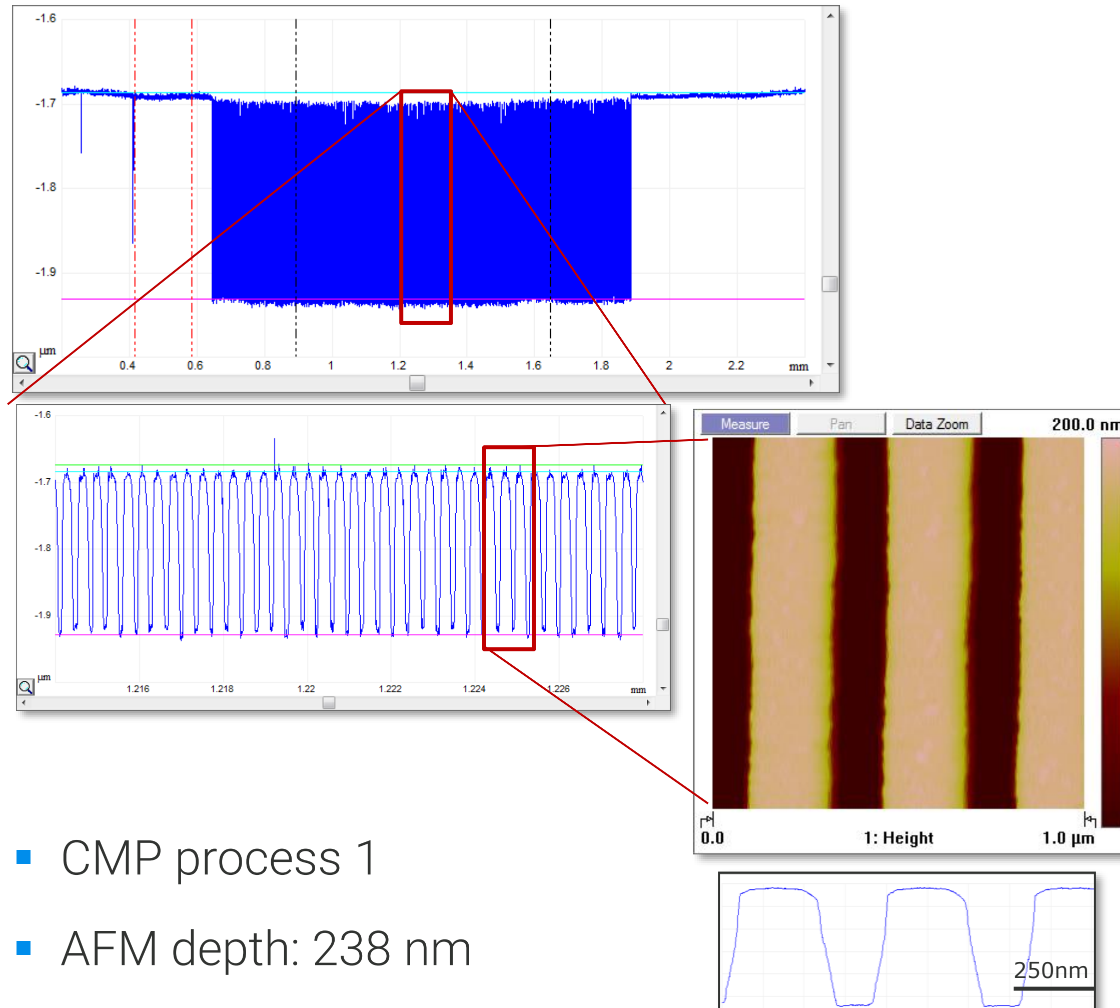
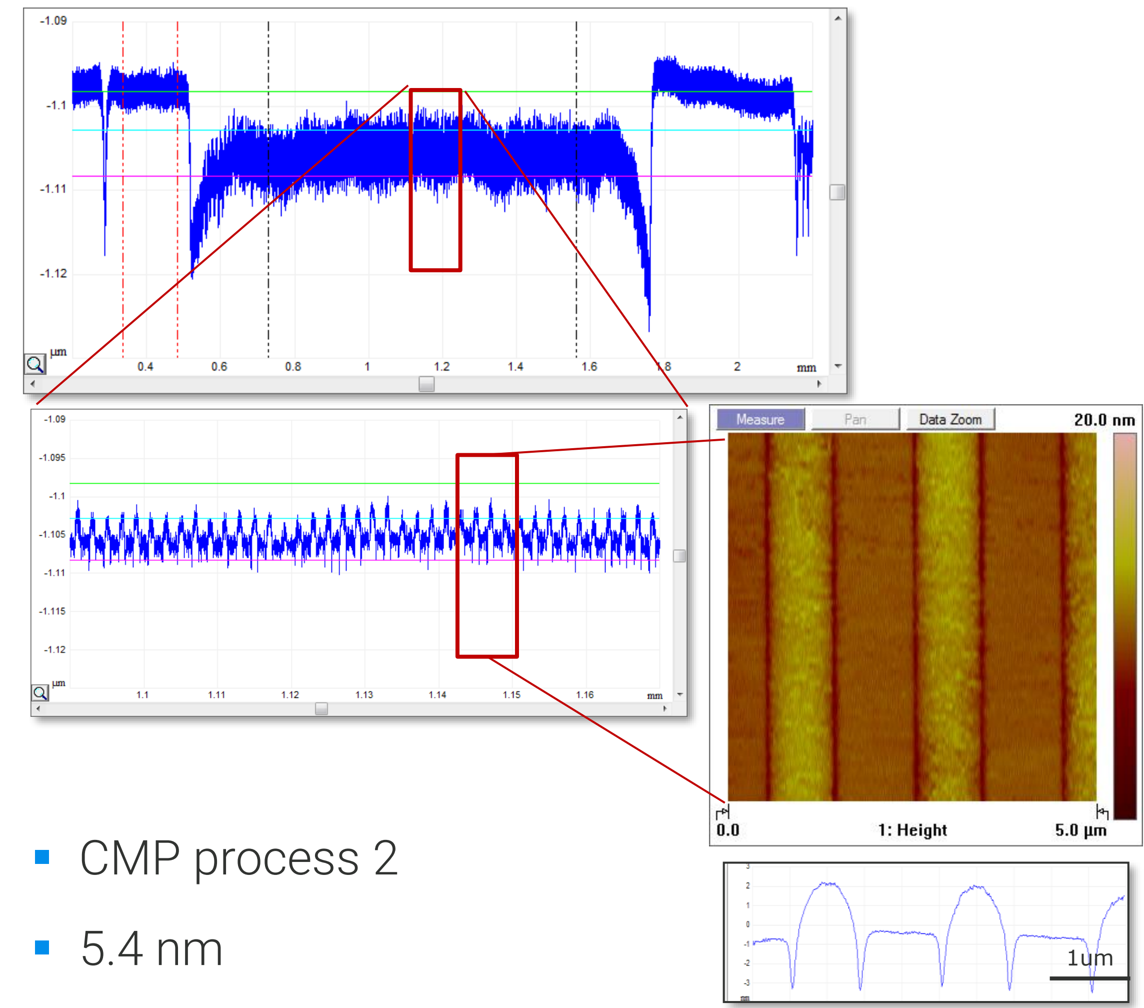
AFM for Profiling & High-Resolution Imaging: Dishing & Erosion



- CMP process 1
- AFM depth: 238 nm



- CMP process 2
- 5.4 nm

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Defects Inspection & Chemical ID of nano-contaminants

- KLARF based navigation to defects, followed by AFM imaging

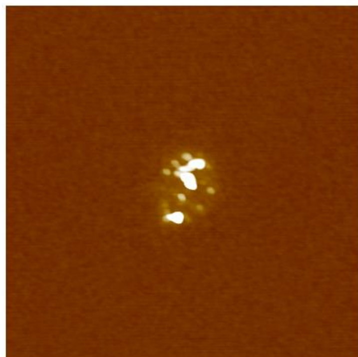
Import KLARF

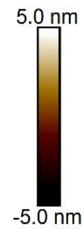
1 Select And Move To Sample Site

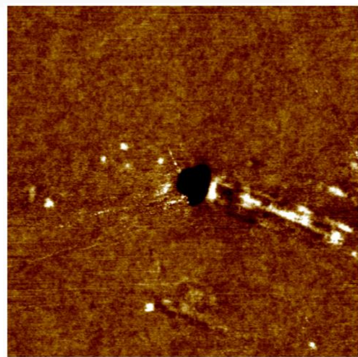
Site #	X Rel (um)	Y Rel (um)	IndX	IndY	SzX (um
1	131921.0000	160433.0000	0	0	0.00
2	156673.0000	94697.0000	0	0	0.00
3	148611.0000	231641.0000	0	0	0.00
4	125632.0000	251039.0000	0	0	0.00
5	253980.0000	178027.0000	0	0	0.00
6	83802.0000	26560.0000	0	0	0.00
7	163251.0000	4121.0000	0	0	0.00
8	124253.0000	4721.0000	0	0	0.00
9	224108.0000	81201.0000	0	0	342.76
10	224149.0000	81245.0000	0	0	260.87
11	224204.0000	81120.0000	0	0	360.31
12	224340.0000	81049.0000	0	0	330.33

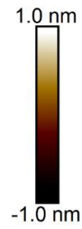
Current Site: 1

Move to Site

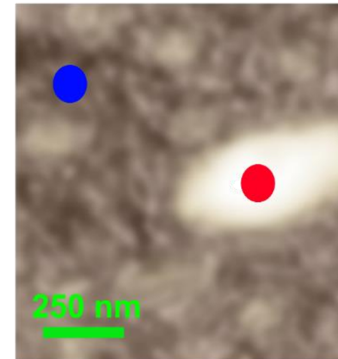


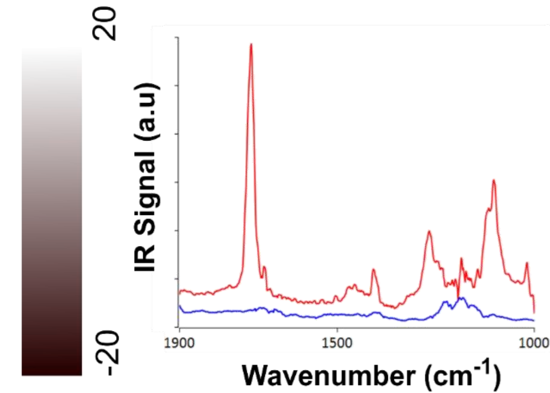


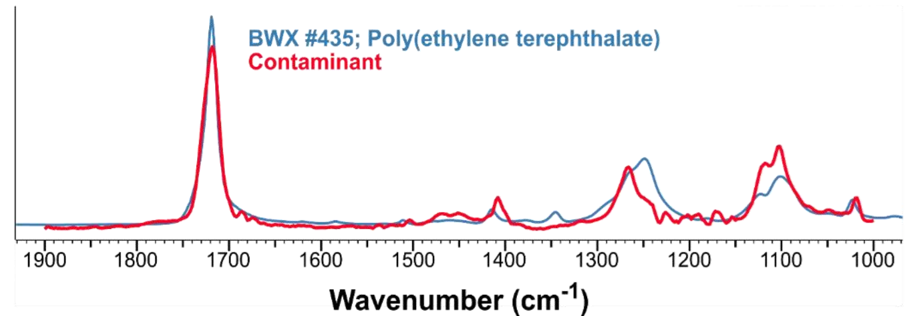




- Chemical identification using AFM-IR (nanometer scale FTIR)







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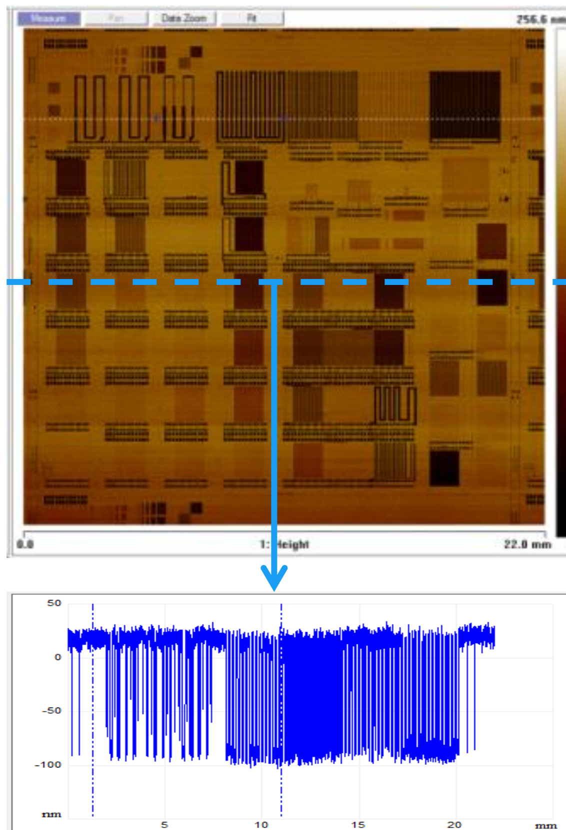
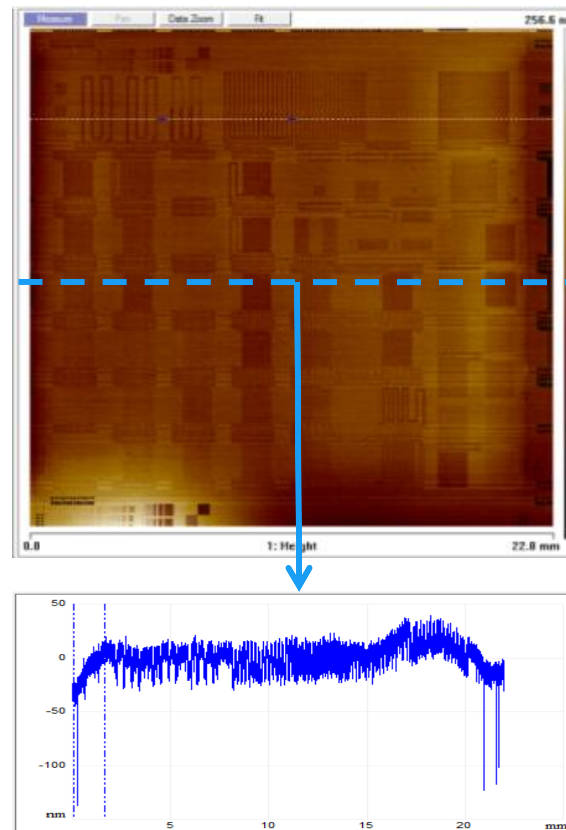
AFM for Large Area Characterization

- 22x22 mm scan, 32x32 µm pixel, 4 hours / image

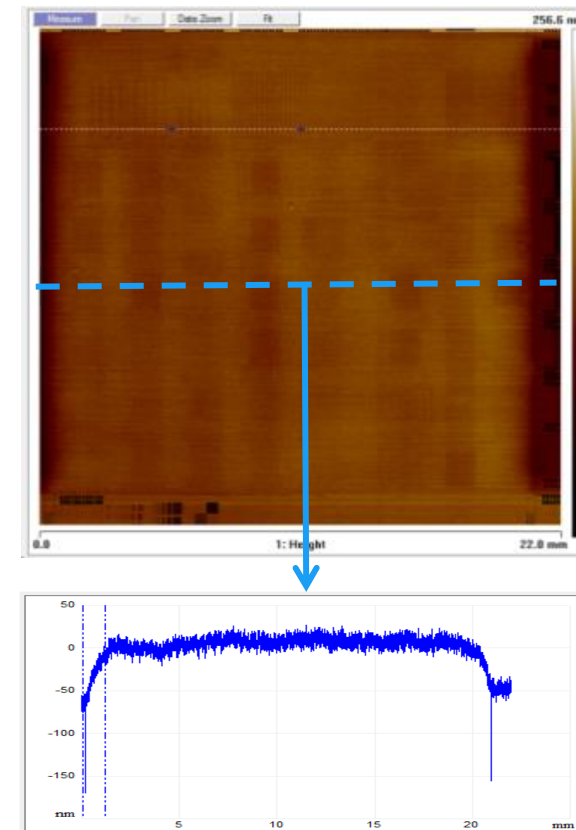
Pre-CMP



Post CMP - Process A



Post CMP - Process B



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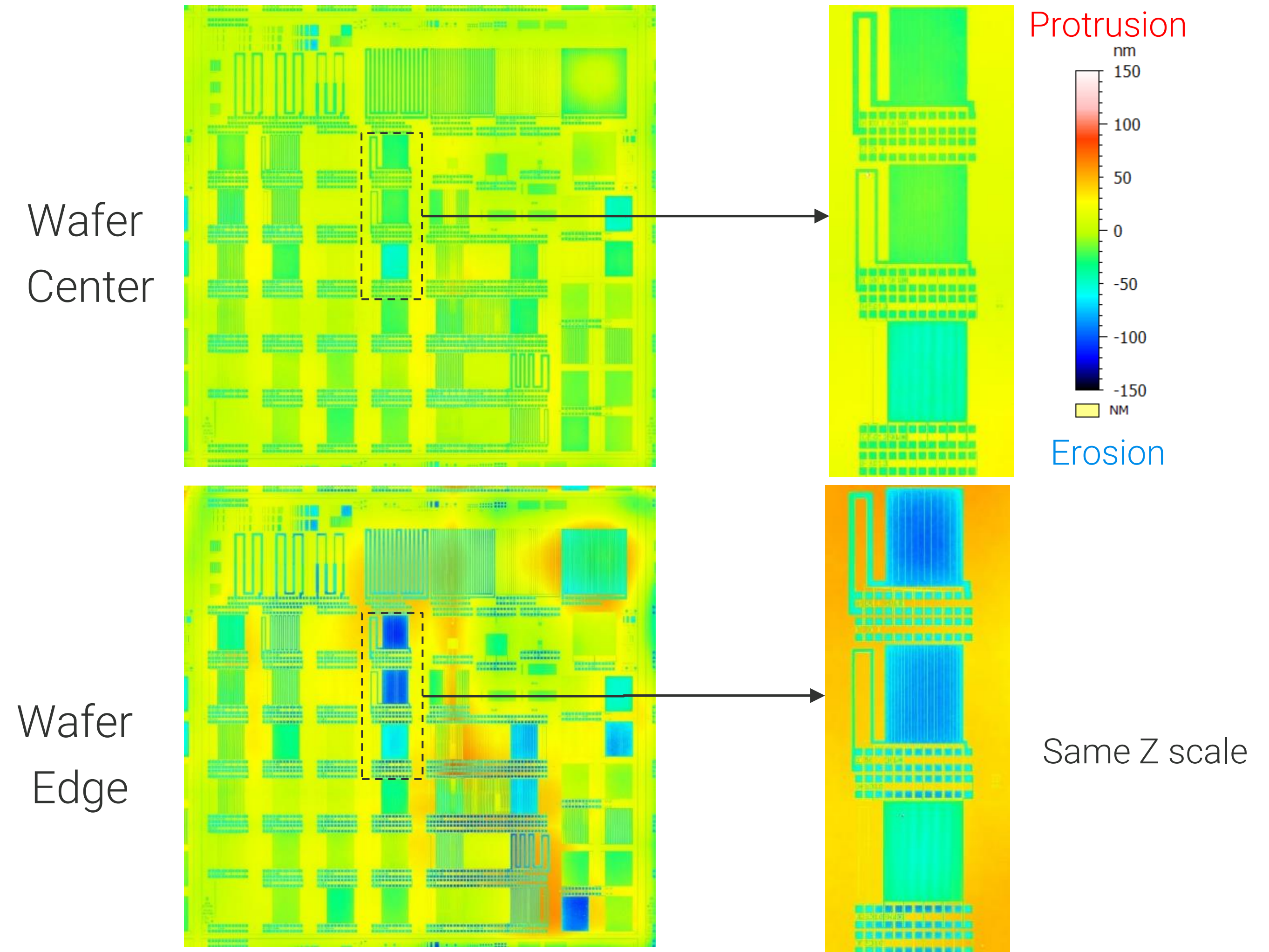
Optical Profiling for Large Area Characterization

- Die size: 22x22 mm
- 2.5 µm lateral resolution
- Number of images < 200
- Measurement time: < 20 minutes
- Height resolution down to Å level



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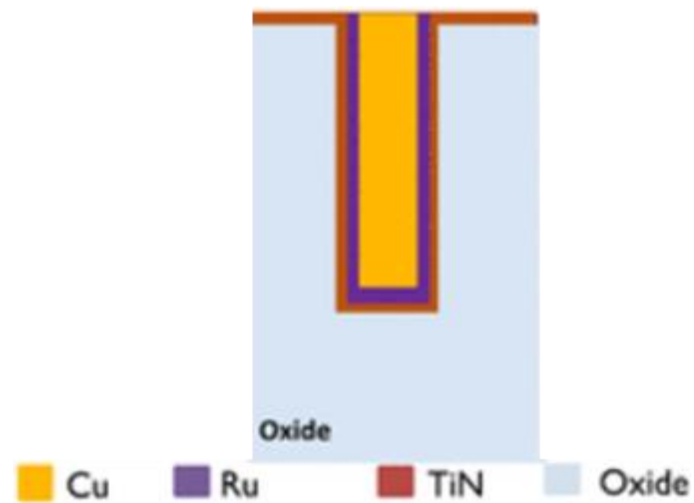
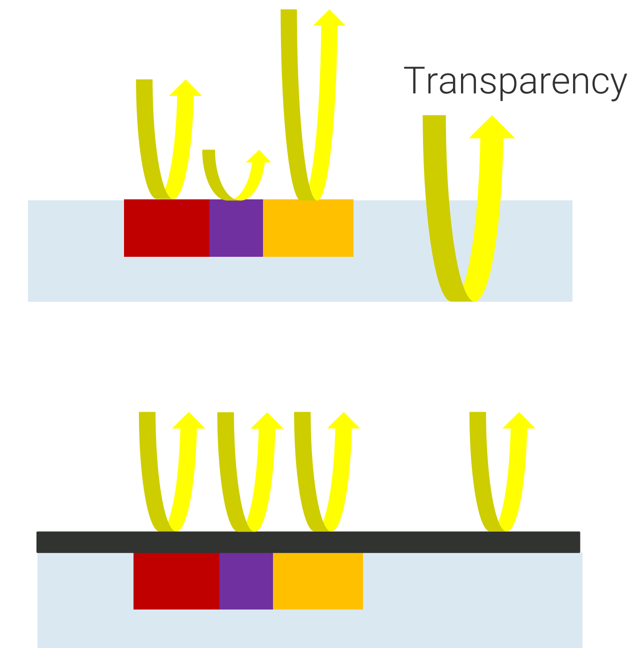
Optical Profiling for Large Area Characterization

- Post-CMP: metallic coating can be required for optical metrology





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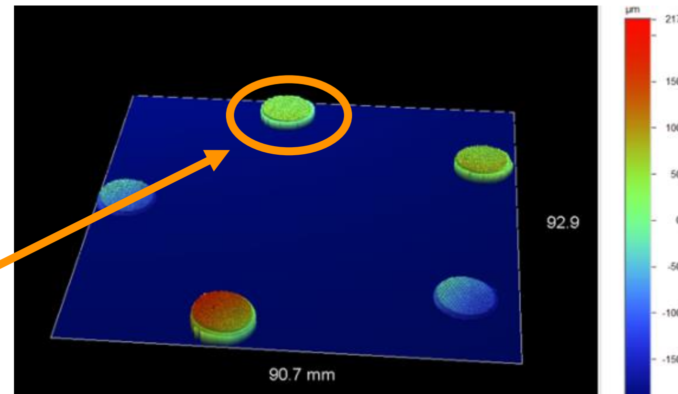
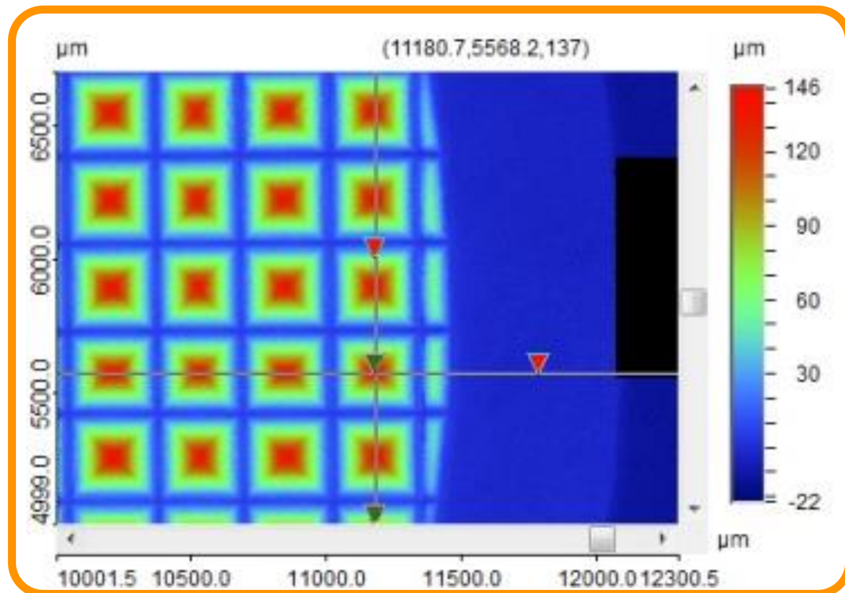
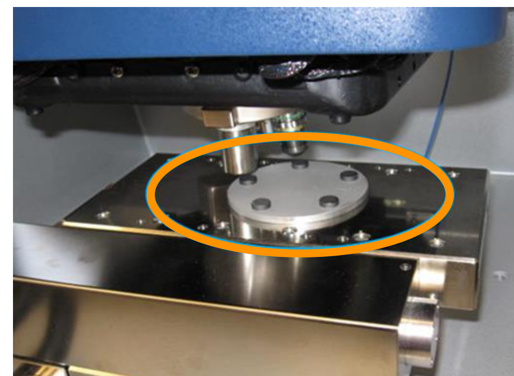
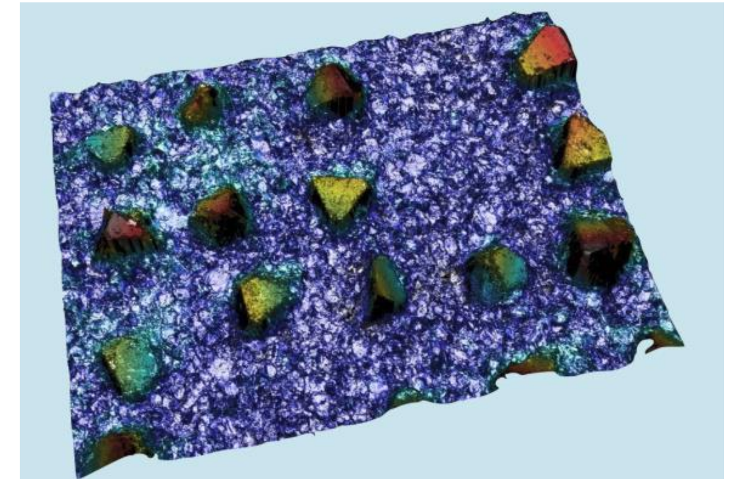
Optical Profiling of Pad Conditioner

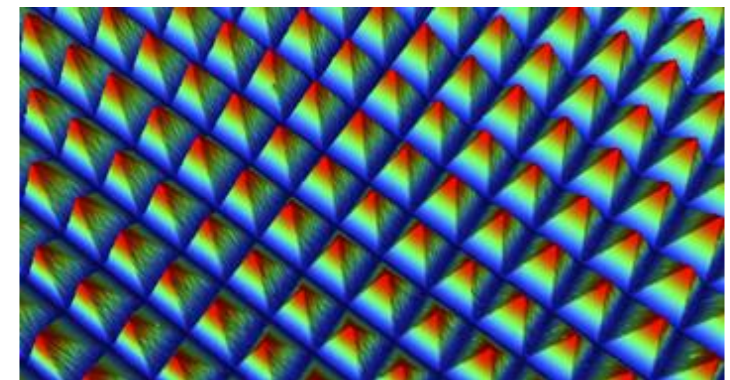
- Accurate, repeatable characterization of pad conditioners – with multiple-site automation & fast data acquisition











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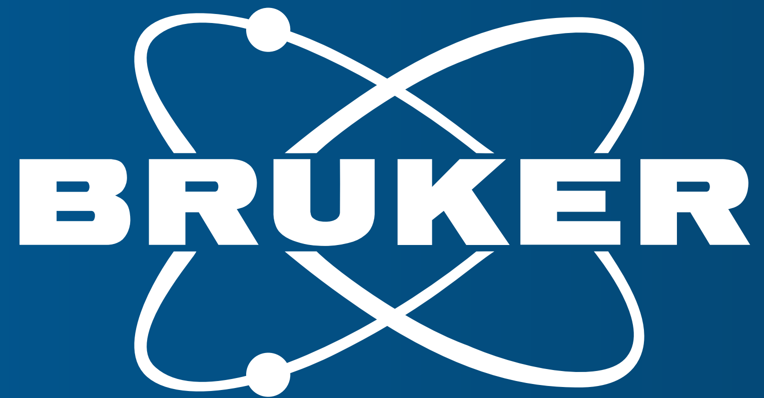

Innovation with Integrity