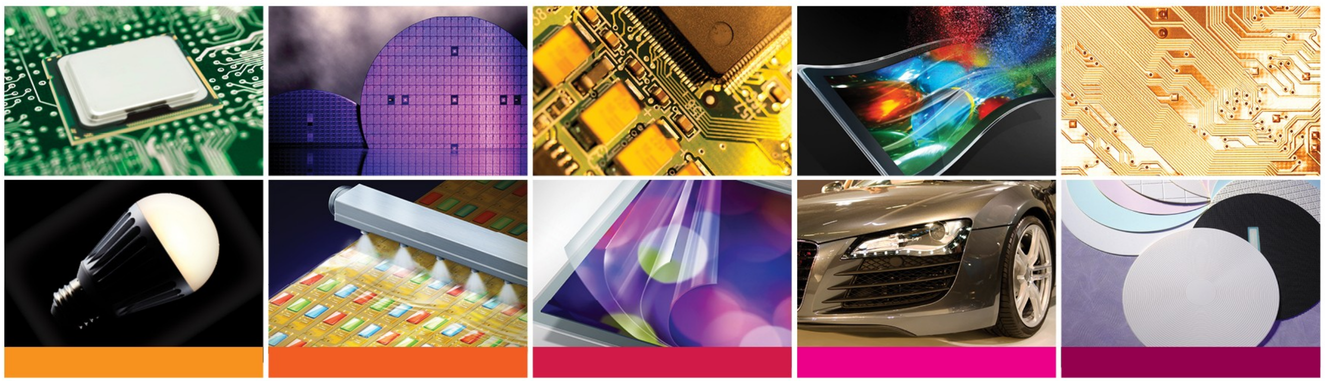
Electronic Materials



Advanced CMP Pad Surface Texture Characterization and Its Impact on Polishing

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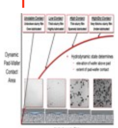
Introduction

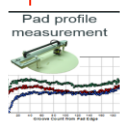
- CMP Pad Characterization Capabilities within Dow
- Pad Surface Texture Characterization Methodology
- Learnings
  - Impact of Conditioning Diamond Properties – Diamond Protrusion
  - Impact of Diamond Wear
  - Impact of Disk Flatness
  - Impact of Polishing Tool – Conditioning System
- Conclusion

CMP Pad Characterization Capabilities within Dow

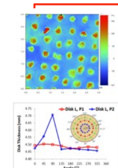
- Variety of characterization capabilities have been developed within Dow for CMP fundamentals, applications and process diagnostics



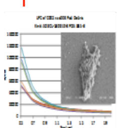
Groove scale hydrodynamic state estimation



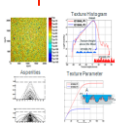
Pad profile measurement



Conditioning Disk Characterization

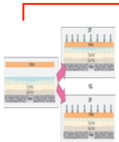


Pad Debris Measurement

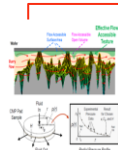


Pad Surface Texture Characterization

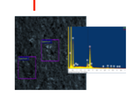
Compressed Texture Characterization



Pad Wafer Compliance

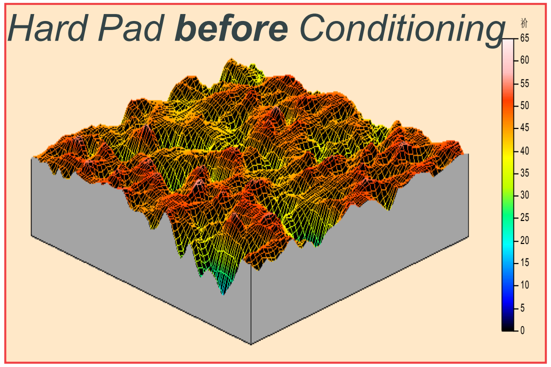


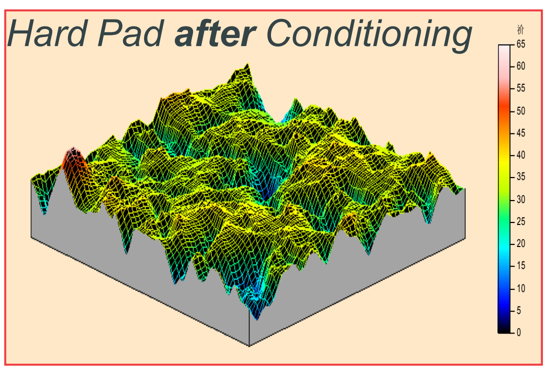
Texture Scale Flow Characterization



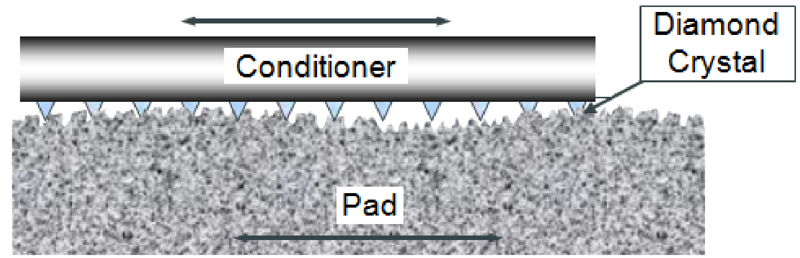
Contamination (SEM)

Pad Conditioning and Surface Texture

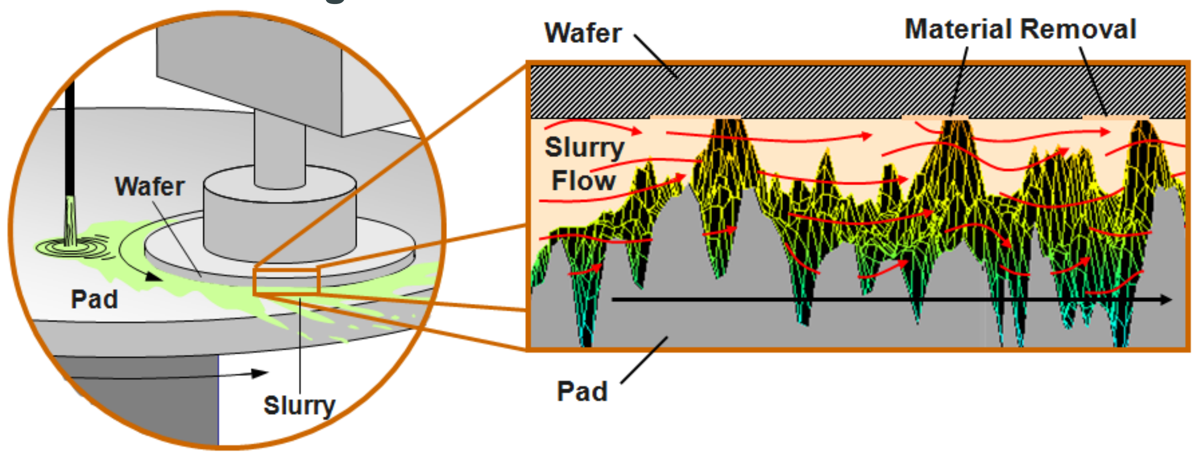




Conditioning



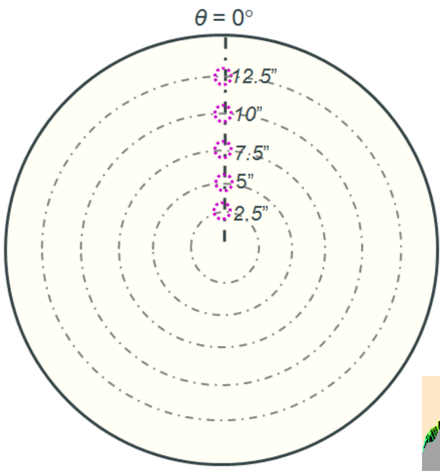
Polishing

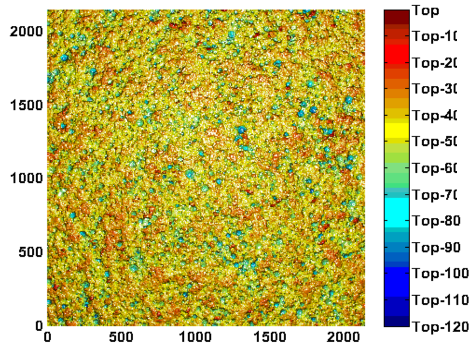


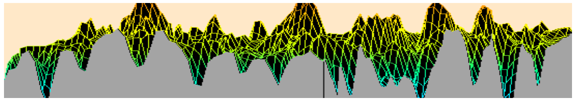
- CMP pad surface texture can significantly impact wafer polishing
- A proper way to quantify pad surface texture is essential to provide an insight into pad conditioning and polishing performance

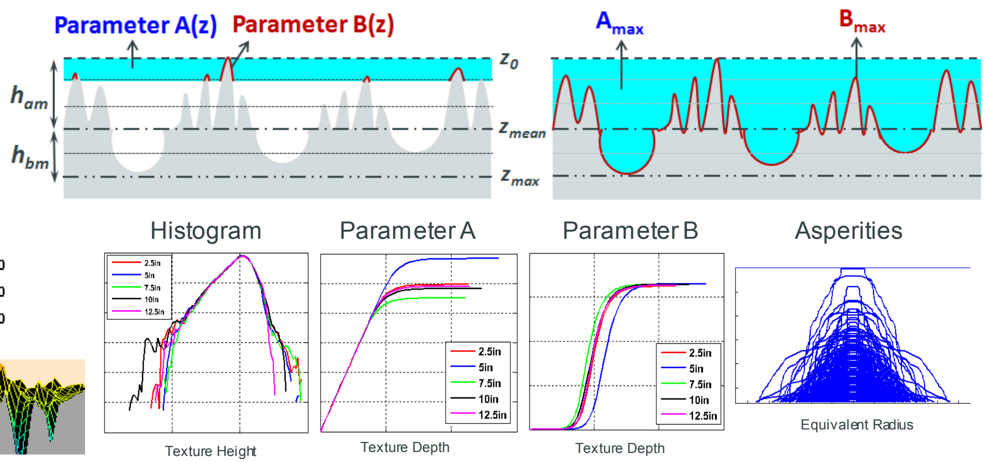
Methodology of Pad Surface Texture Characterization

Experimental → 3D Topography → Custom Data Analysis









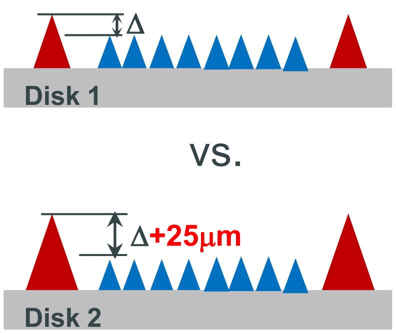
- High resolution fast speed optical characterization is used to scan representative regions on the pad to obtain 3D surface topography
  - Missing data is minimized to ensure high data quality
- Custom analysis is used to obtain texture characteristics impacting polishing performance including texture histogram, key parameters (e.g. A(z) and B(z)), their distributions and asperity properties

Learning 1

Impact of Conditioning Diamond Properties – Diamond Protrusion

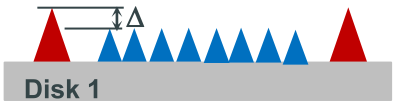
Disk	Disk type	Diamond Type	Diamond Protrusion Difference between bimodal diamonds	Pad Material	Tool/Process
1	same	bimodal	$\Delta_{protrusion}$	IC1000™	same (DI water conditioning only)
2			$\Delta_{protrusion}$ **+ 25μm**		

- Both disks have same design and types of diamonds but diamond protrusion difference between bimodal diamonds differs by 25μm
- Reduced diamond protrusion difference leads to shallower pad surface texture, better texture uniformity and lower pad cut rate

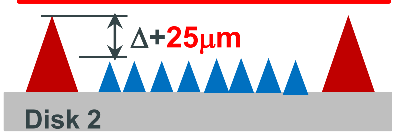


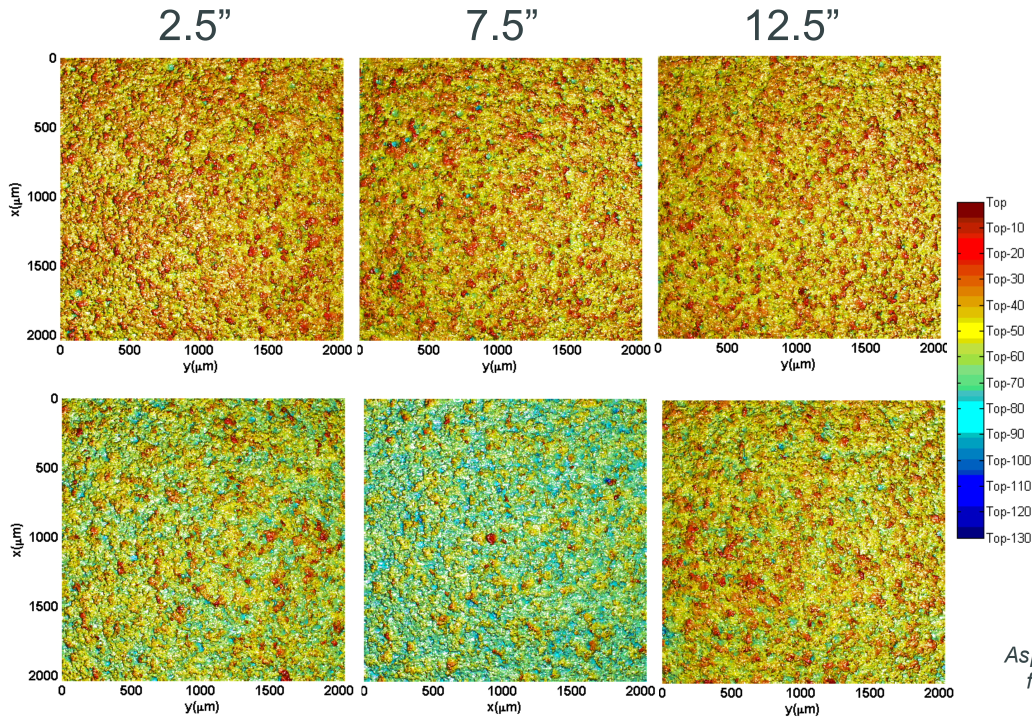
Pad Surface Texture (2x2mm^2)

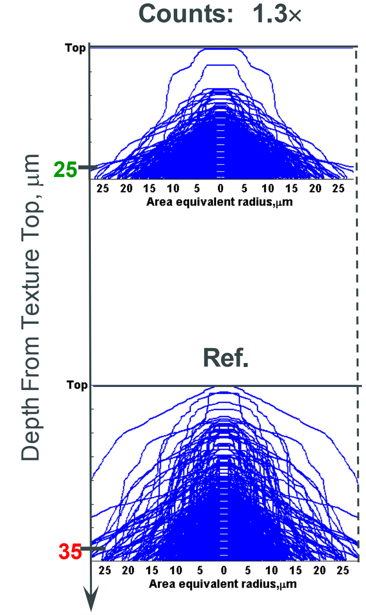
Pad 1
Disk **1** with
small $\Delta_{protrusion}$



Pad 2
Disk **2** with
large $\Delta_{protrusion}$

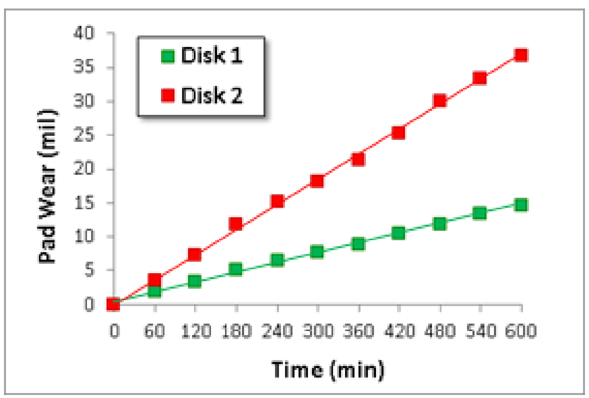






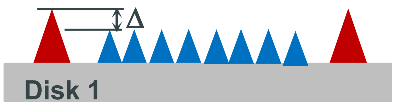
Asperities obtained at the same height percent from texture top relative to the mean plane

- Compared to pad 2, pad 1/disk 1 exhibited shallower and more uniform texture across pad radii, finer asperities in greater counts, and less pad wear due to less diamond protrusion difference

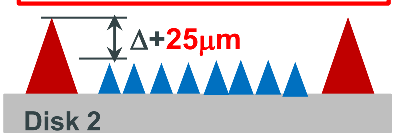


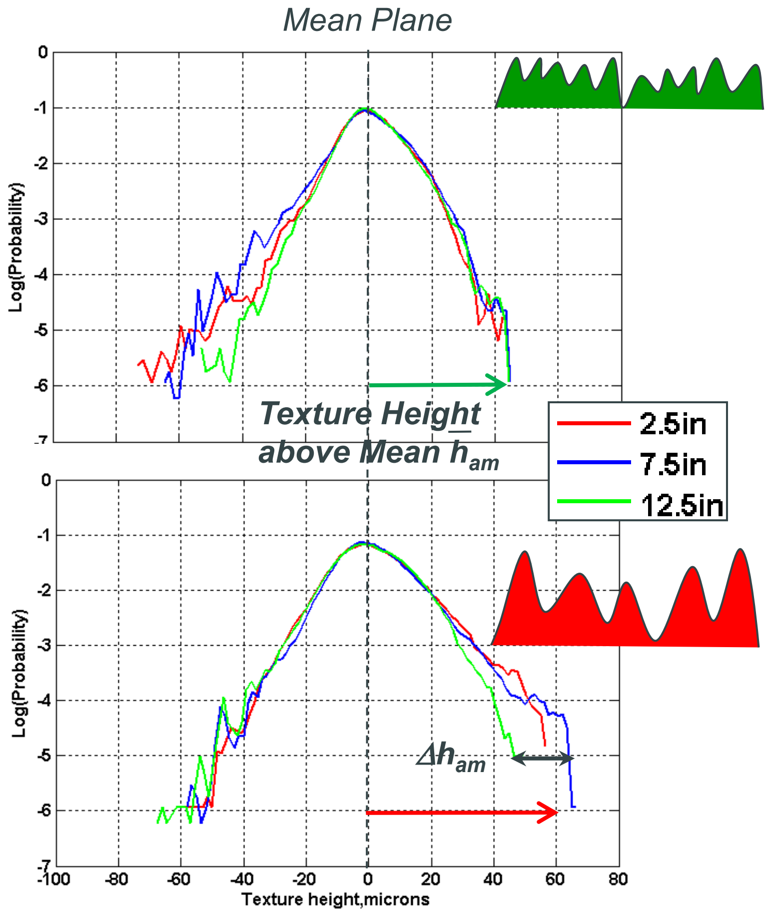
Texture Histogram

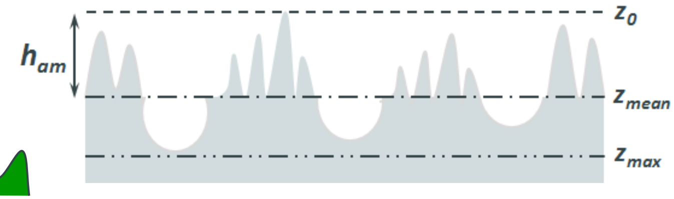
Pad 1
Disk **1** with
small $\Delta_{protrusion}$

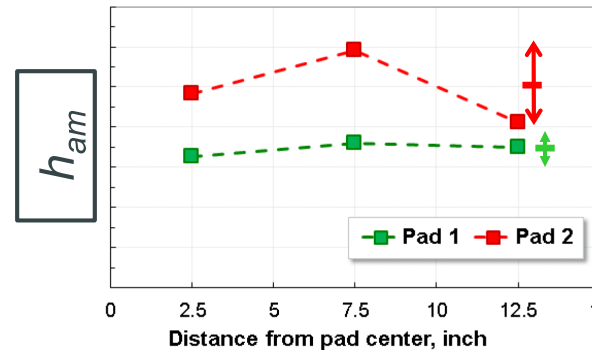


Pad 2
Disk **2** with
large $\Delta_{protrusion}$





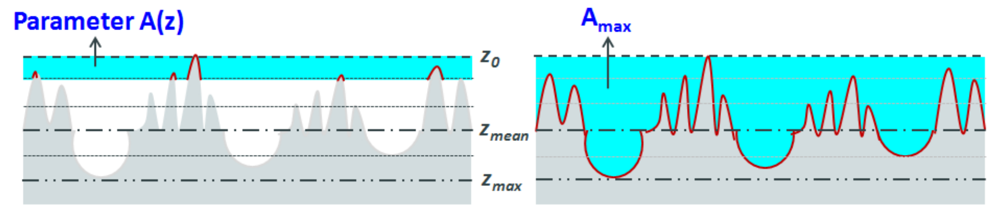




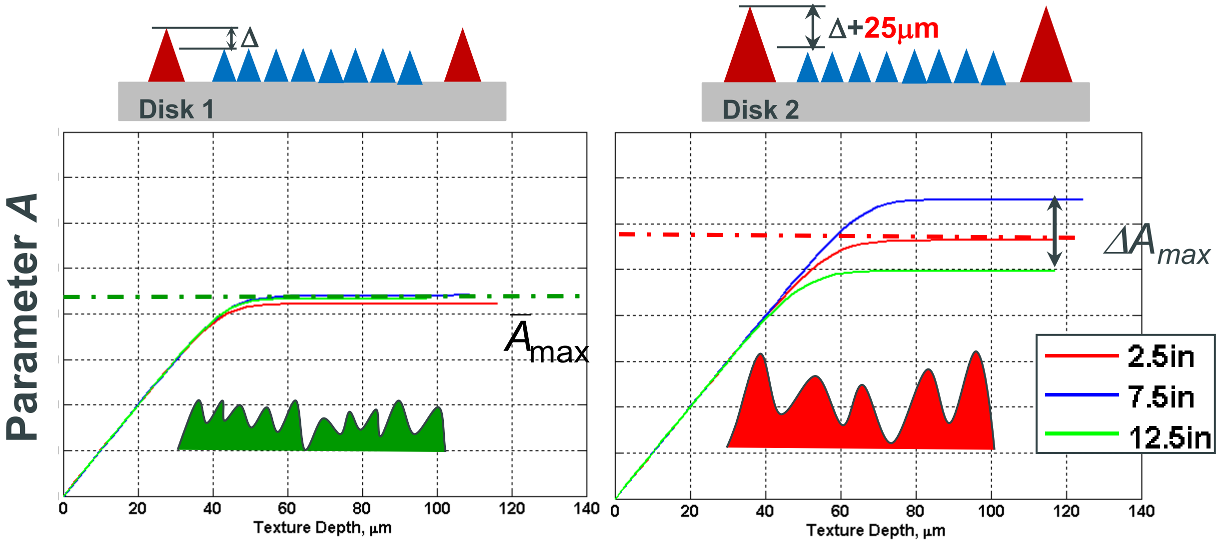
Normalized h_{am}	Pad 1		Pad 2
Avg. h_{am}	0.75	<	1
STDEV of h_{am}	0.22	<	1

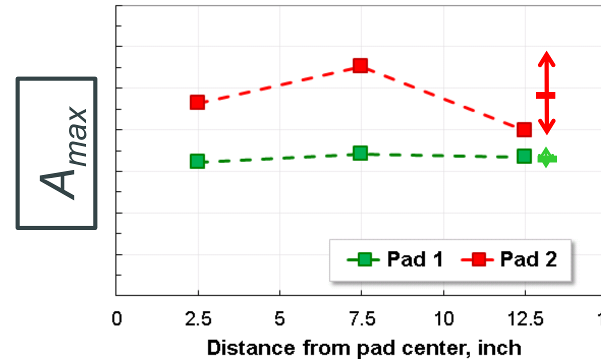
- Compared to pad 2, pad 1 exhibited smaller texture height above mean (h_{am}) on average and less variation across pad radii
  - Indicative of difference in asperities above the mean plane

Texture Parameter *A*



Pad 1, Disk **1** with ***small*** $\Delta_{protrusion}$	Pad 2, Disk **2** with ***large*** $\Delta_{protrusion}$

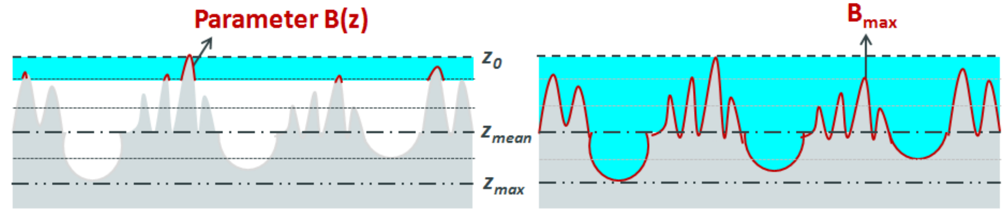




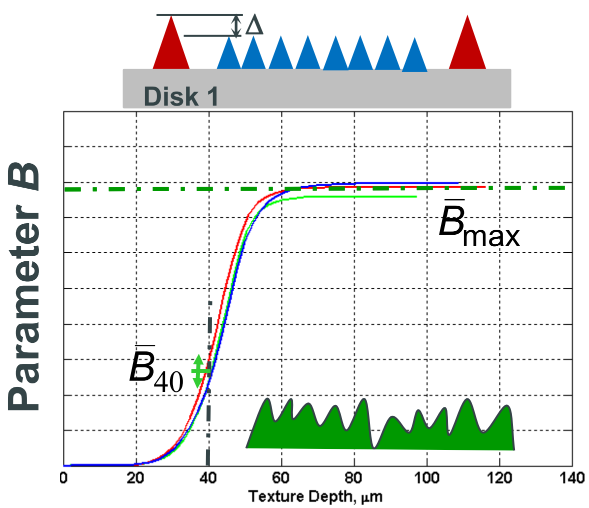
Normalized *A*	Pad 1		Pad 2
Avg. A_{max}	0.75	<	1
STDEV of A_{max}	0.12	<	1

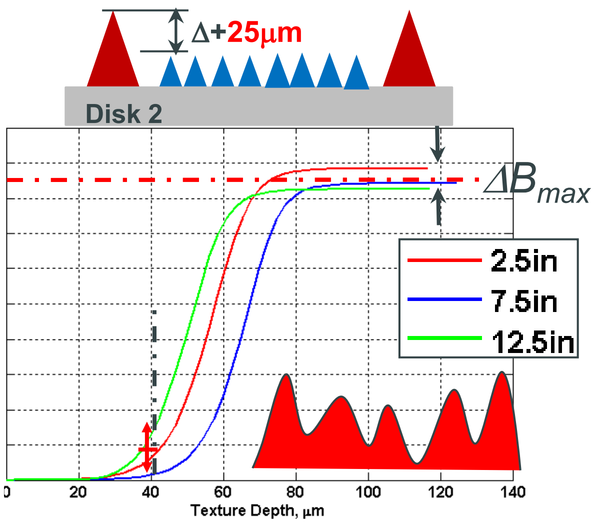
- Texture parameter *A* is a descriptor of texture scale volume (as a function of texture depth) available for slurry transportation
  - A_{max} indicates the maximum capacity
- Pad 1 exhibited smaller A_{max} on average and less variation than pad 2
  - Indicative of slurry transportation difference at texture scale

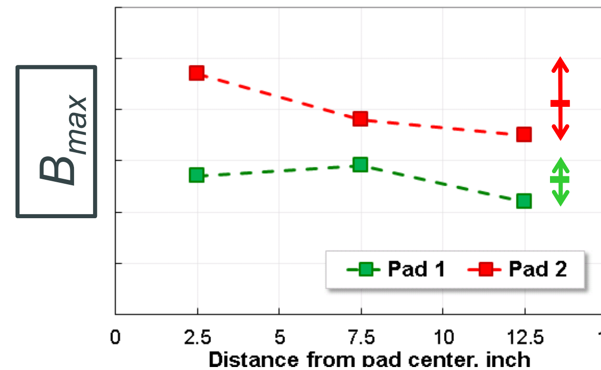
Texture Parameter *B*



Pad 1, Disk **1** with ***small*** $\Delta_{protrusion}$	Pad 2, Disk **2** with ***large*** $\Delta_{protrusion}$







Normalized *B*	Pad 1		Pad 2
Avg. B_{max}	0.92	<	1
STDEV of B_{max}	0.66	<	1

- *B* is a descriptor of projected surface area (a function of texture depth in ‘S’ shape) available for slurry and pad-wafer contact at texture scale
- Pad 1 exhibited different B(z) profile, smaller B_{max} on average, and less variation than pad 2 indicating higher tendency to hydroplane at texture scale given other properties same

Learning 2

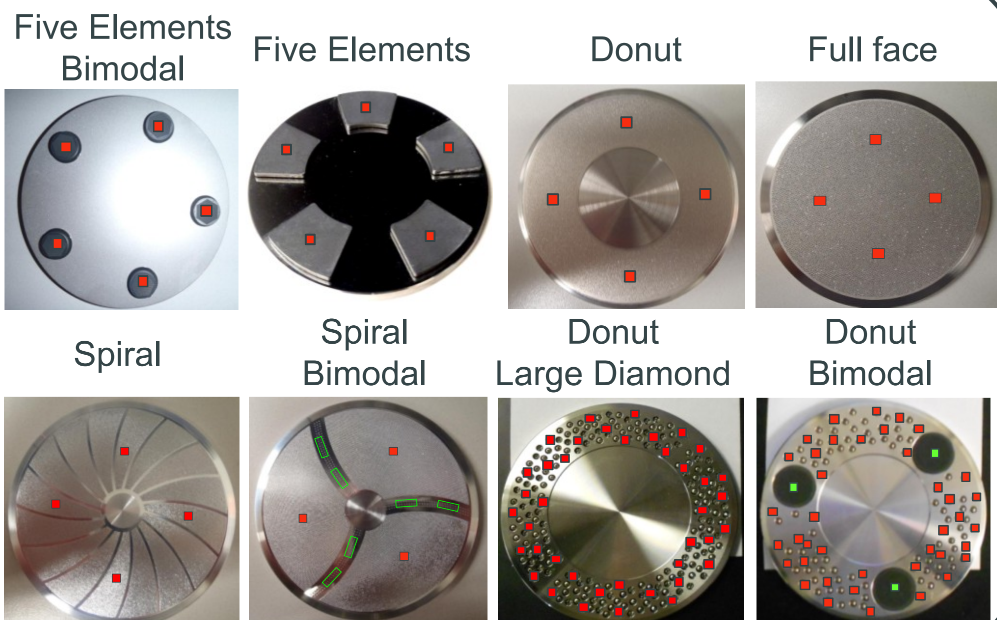
Impact of Diamond Wear

Disk	Disk Type/ Diamond Type	Diamond Wear	Pad Material	Polisher/Process
1	same	More, Blunt	IC1000™	same (STI polish)
2		Minor, Sharp		

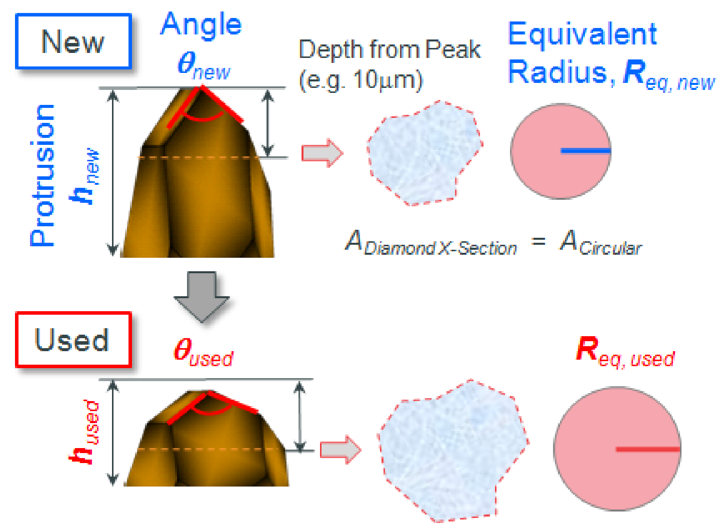
- Difference in diamond wear for a given process is clearly linked to resulting pad surface texture and pad wear/cut rate
- Diamond disk with more wear leads to shallower texture and lower pad cut rate

Conditioner Characterization Methodology

Different Disk Configurations



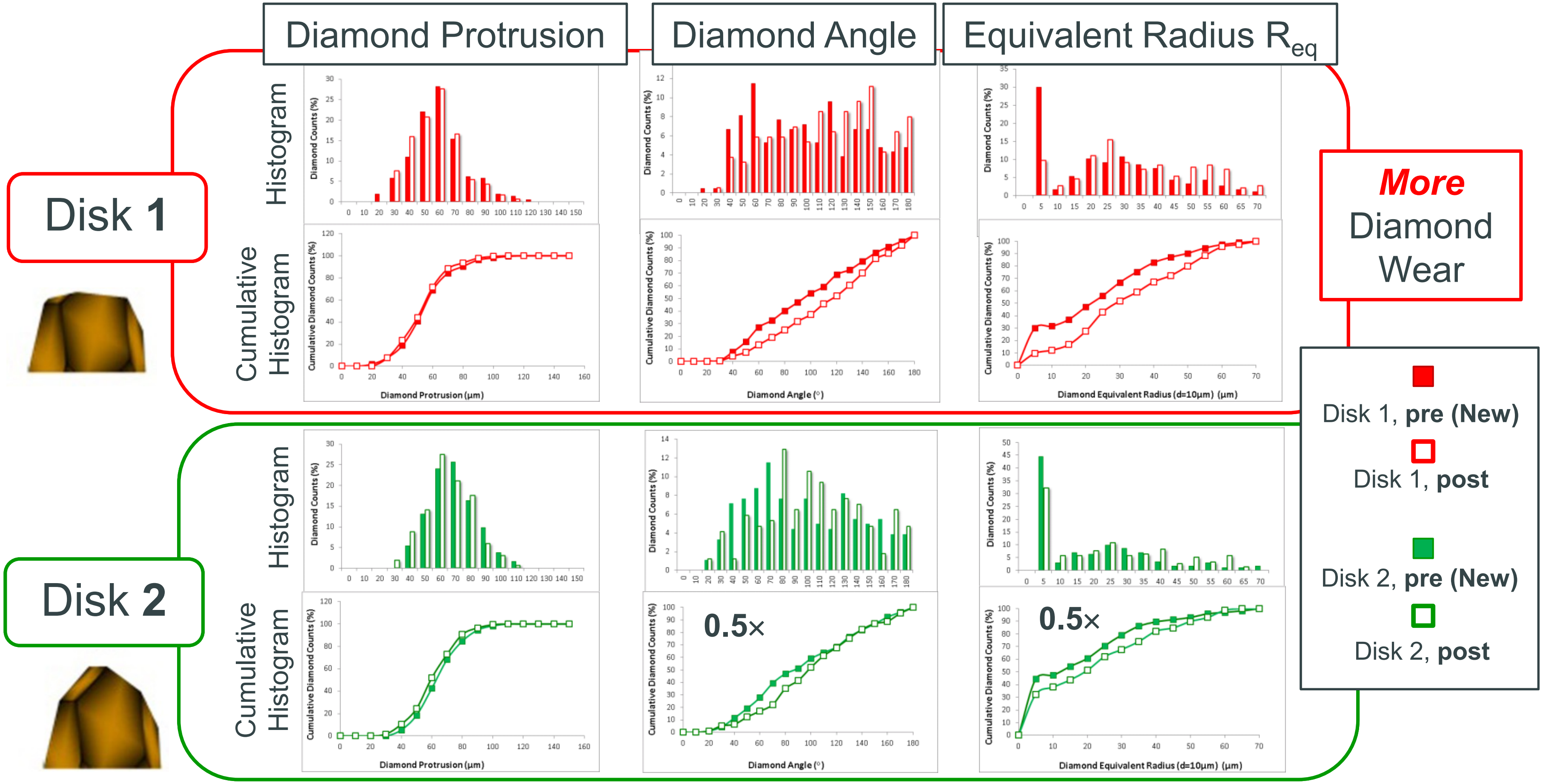
Analysis of Diamond Characteristics



Z. Liu, J. McCormick, T. Buley, Conditioner characterization and implementation for impacts of diamonds on CMP pad texture and performance, IEEE proc. 2015 ICPT, pp 285, 2015

- Interferometer is used to scan representative regions on the disk to obtain data of >100 diamonds
- Custom analysis is used to obtain individual diamond characteristics including protrusion, angle (360°-averaged) and equivalent radius (R_{eq})

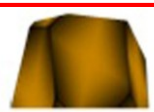
Characterization of Diamond Wear



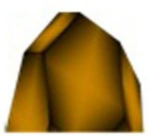
- Histogram shift is used to quantify diamond wear
- Relative to disk 1, disk 2 exhibited less diamond wear in diamond angle (0.5×) and equivalent radius (0.5×) primarily due to diamond properties

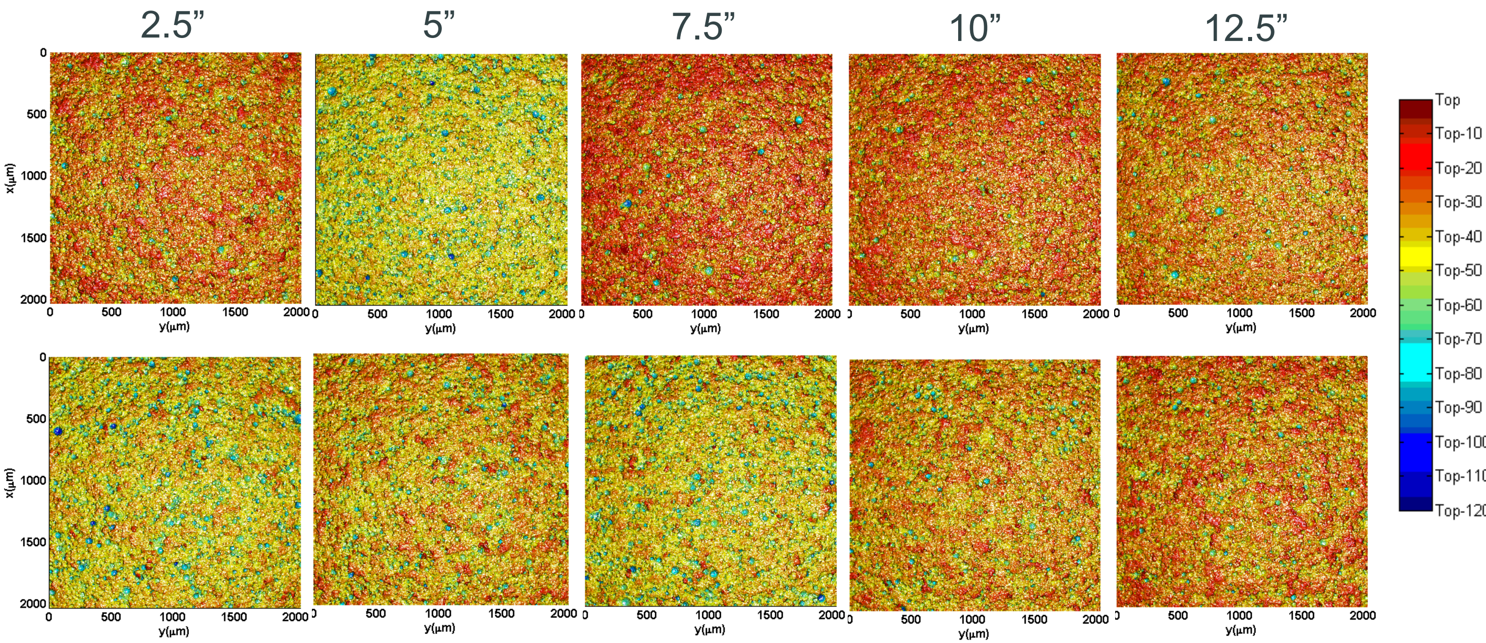
Pad Surface Texture (2x2mm^2)

Pad **1**/Disk **1** (***More wear / Blunt***)

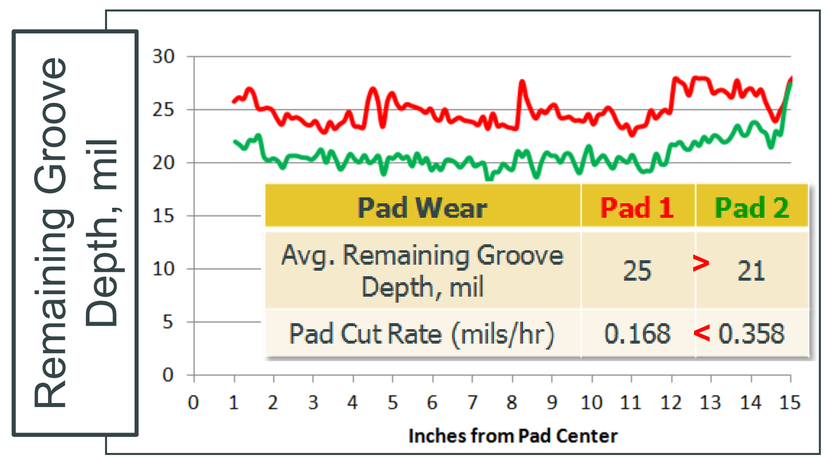


Pad **2** Disk **2**



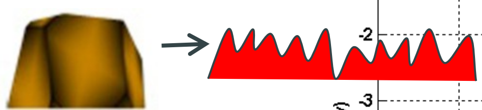


- Relative to pad 1, pad 2 exhibited deeper texture on average and greater pad cut rate with less remaining groove for given process, impacted by diamond wear

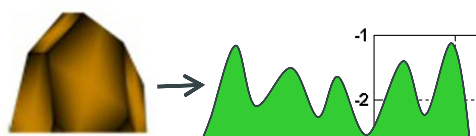


Pad Wear	Pad 1		Pad 2
Avg. Remaining Groove Depth, mil	25	>	21
Pad Cut Rate (mils/hr)	0.168	<	0.358

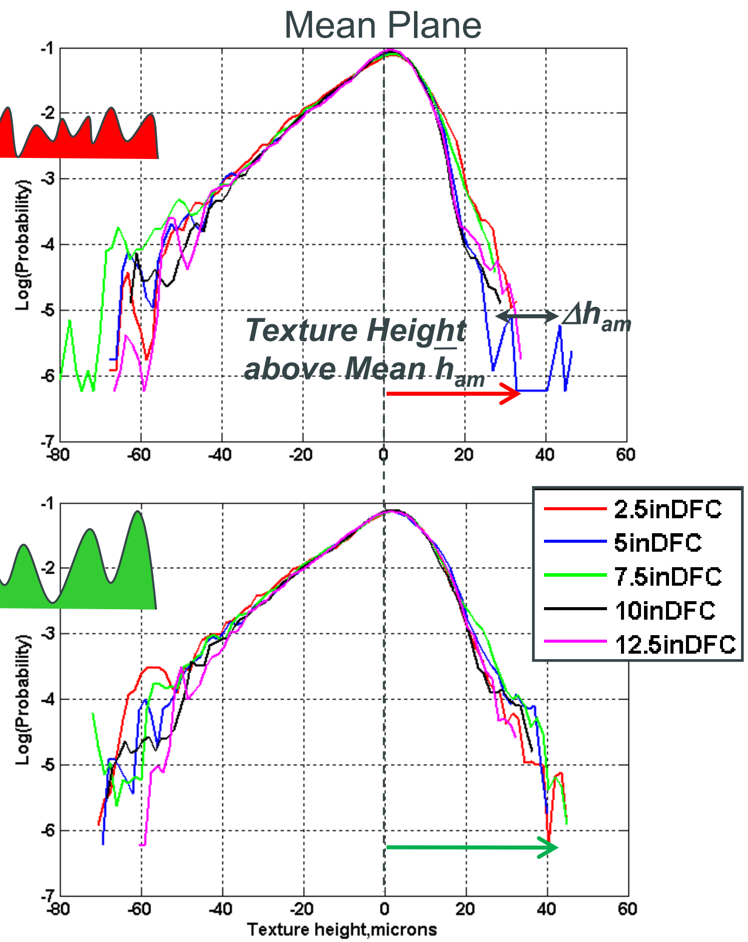
Texture Histogram

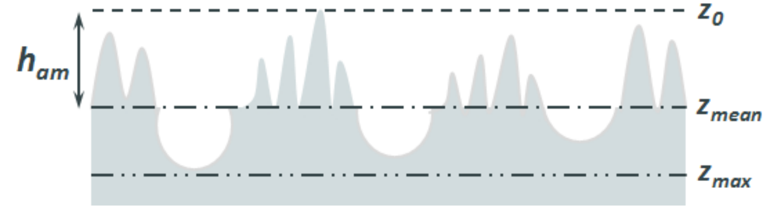


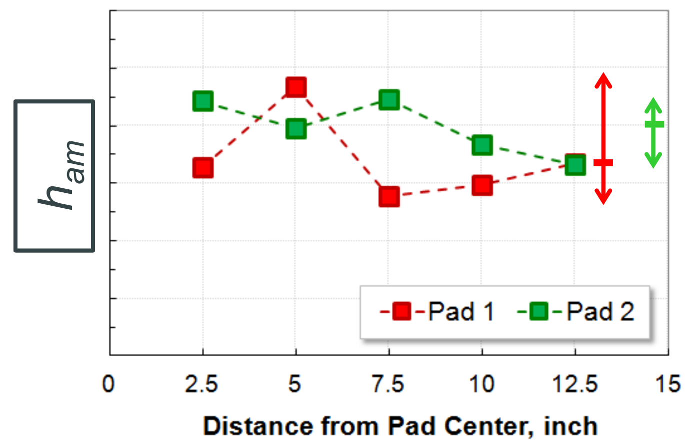
Pad **1**/Disk **1** (***More wear /Blunt***)



Pad **2** Disk **2**



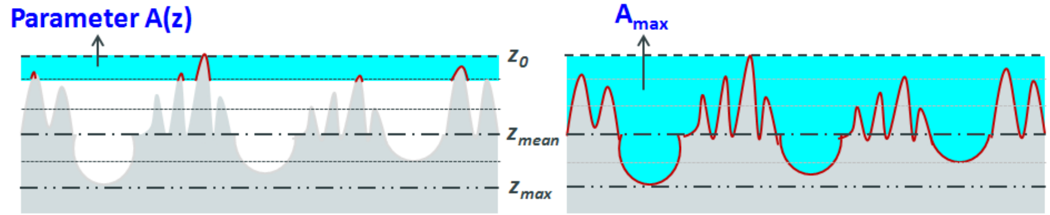




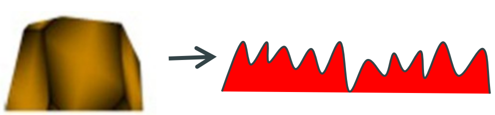
Normalized h_{am}	Pad 1	Pad 2
Avg. h_{am}	0.85 <	1
STDEV of h_{am}	1.62 >	1

- Compared to pad 1, pad 2 exhibited greater texture height above the mean (h_{am}) on average and less variation across pad radii

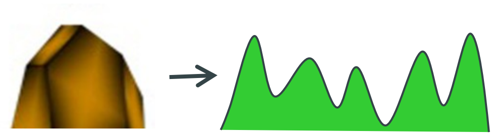
Texture Parameter *A*

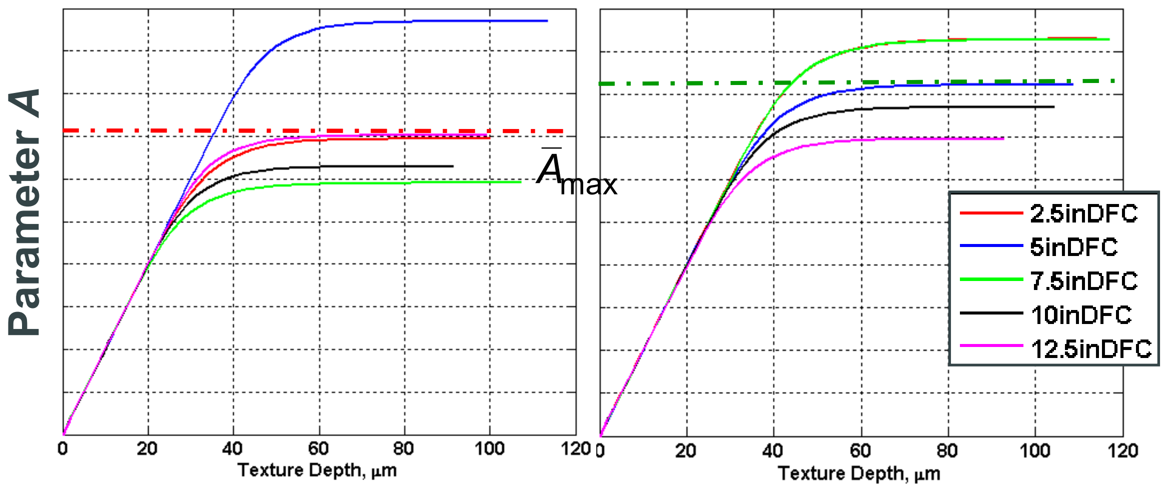


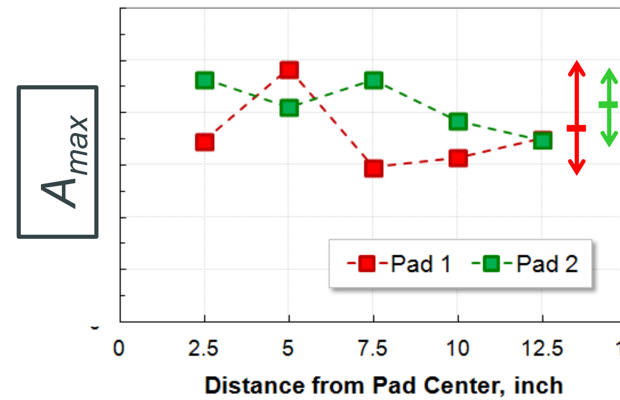
Pad **1**/Disk **1**
(***More wear/Blunt***)



Pad **2** /Disk **2**



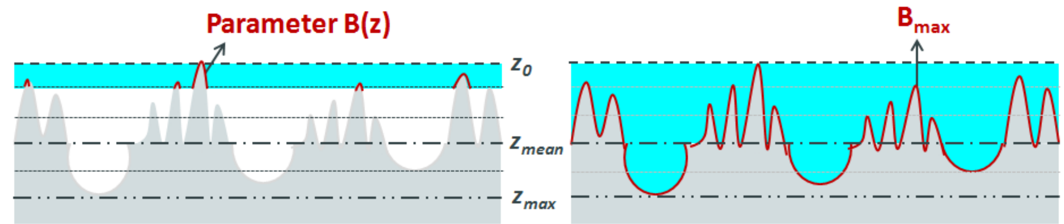




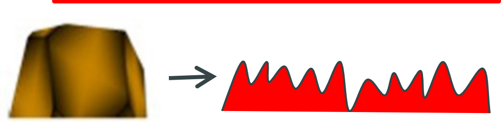
Normalized *A*	**Pad 1**		**Pad 2**
Avg. A_{max}	0.87	$<$	1
STDEV of A_{max}	1.4	$>$	1

- Compared to pad 1, pad 2 exhibited greater texture parameter A_{max} on average and less variation across pad radii impacted by diamond wear

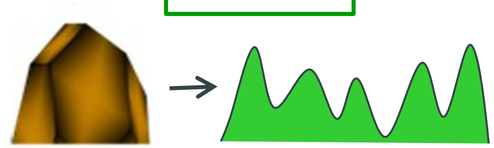
Texture Parameter *B*

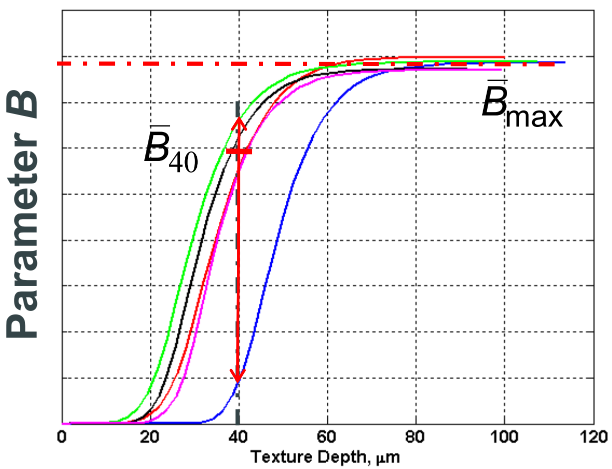


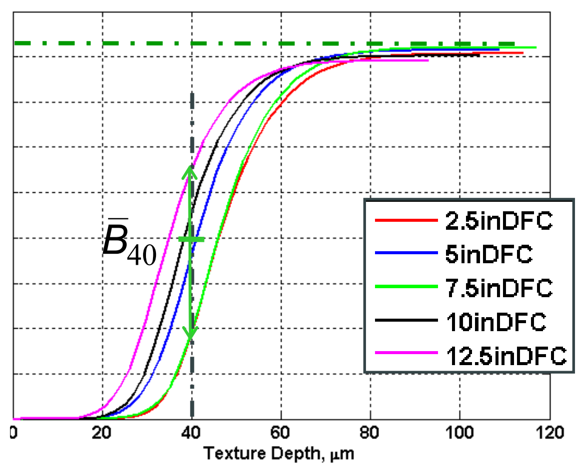
Pad **1**/Disk **1**
(***More wear/Blunt***)

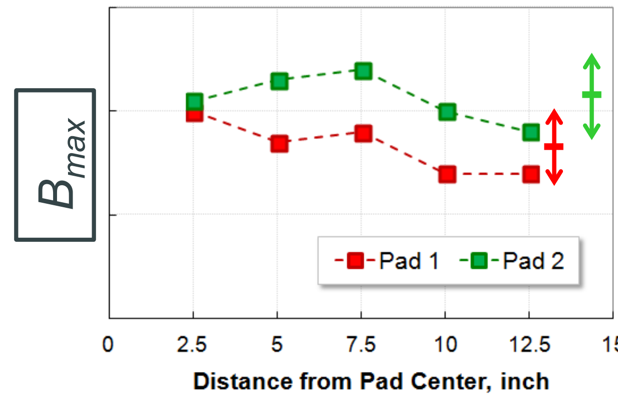


Pad **2**
Disk **2**









Normalized *B*	Pad 1		Pad 2
Avg. B_{max}	0.92	<	1
STDEV of B_{max}	1.5	>	1

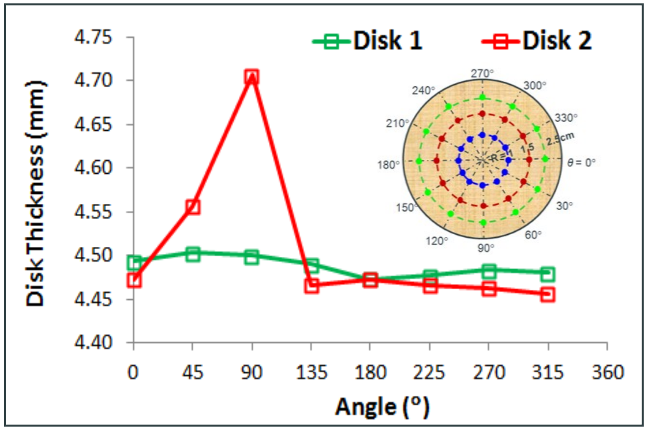
- Compared to pad 1, pad 2 exhibited different profile of B(z), larger texture B_{max} on average primarily due to greater texture depth, and less variation

Learning 3

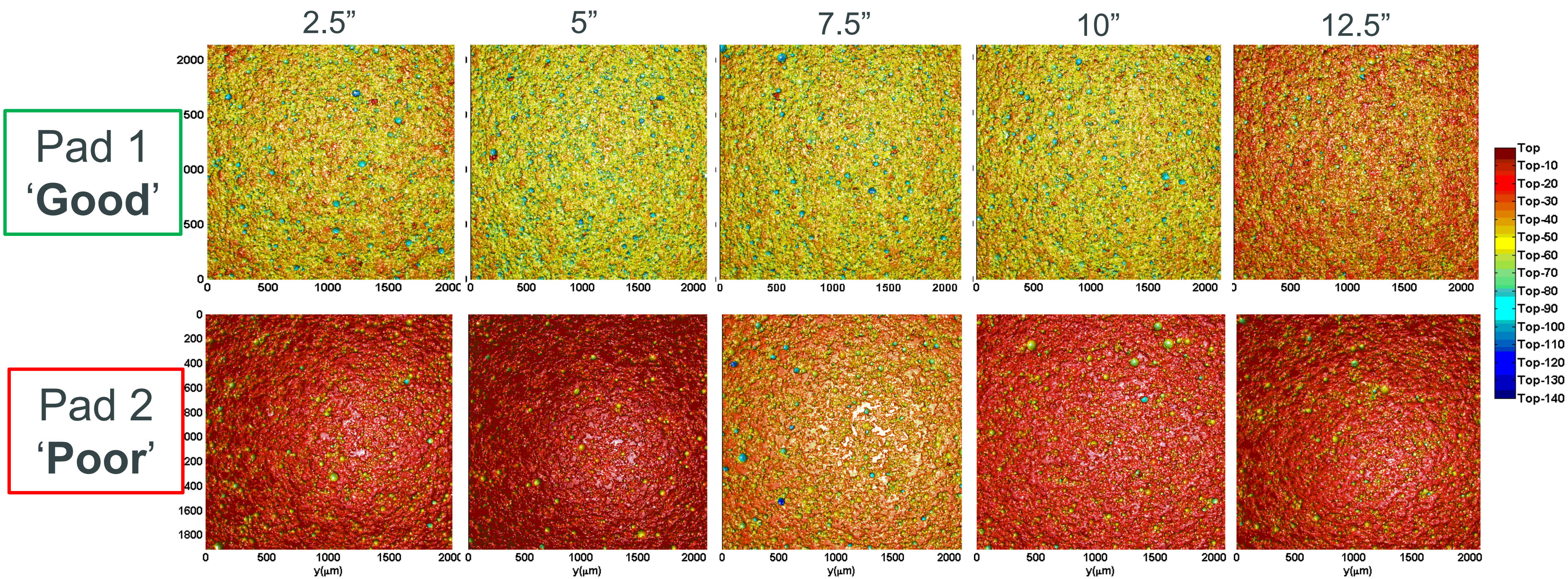
Impact of Disk Flatness

Disk	Disk Type	Disk Age	Pad Material	Polisher/Process	Polish Note
1	same	same	IC1000™	same (STI polish)	***Good***
2					***Poor, Unstable RR***

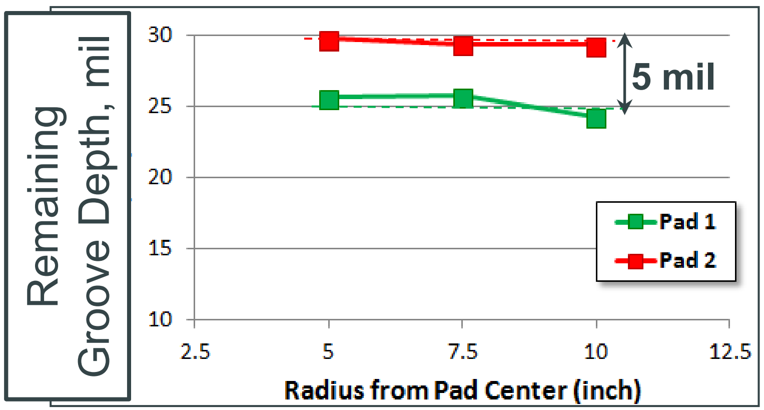
- Disk base flatness property can significantly impact pad conditioning and resulting surface texture leading to problematic polishing performance



Pad Surface Texture ($2x2mm^2$)

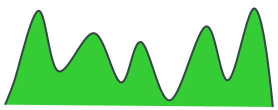


- Relative to pad 1, pad 2 exhibited much shallower texture from pad center to edge and significantly lower pad cut rate with little groove wear for given process

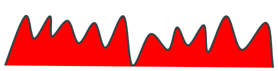


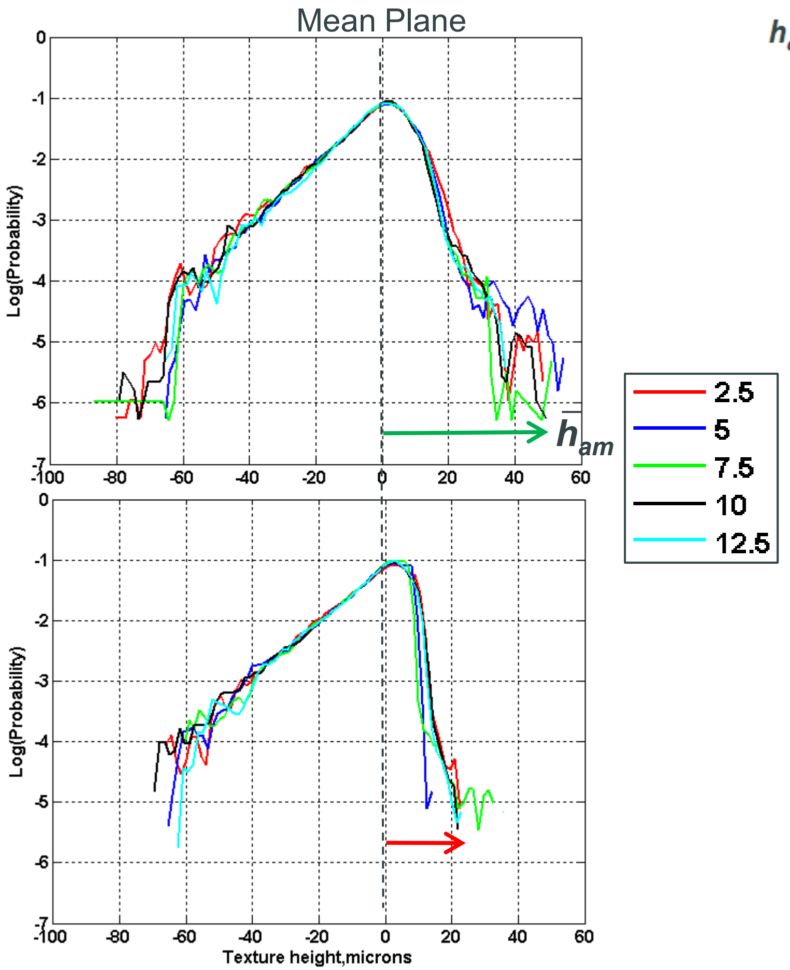
Texture Histogram

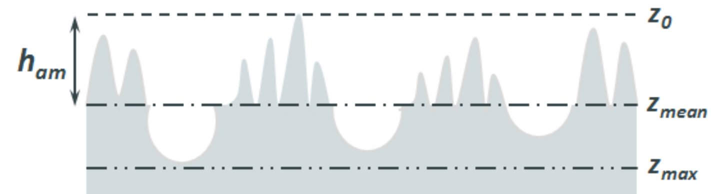
Pad 1
'Good'

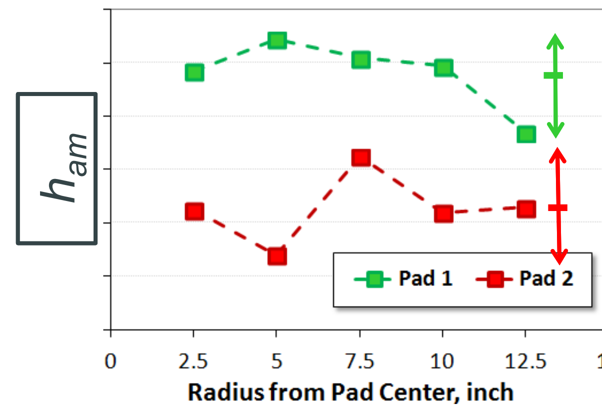


Pad 2
'Poor'





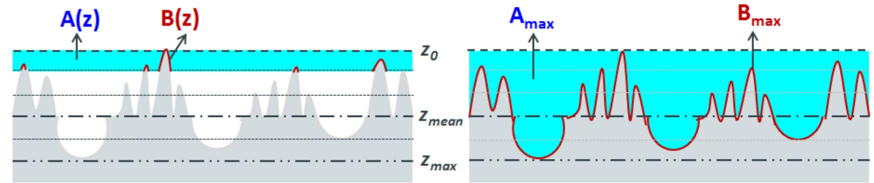


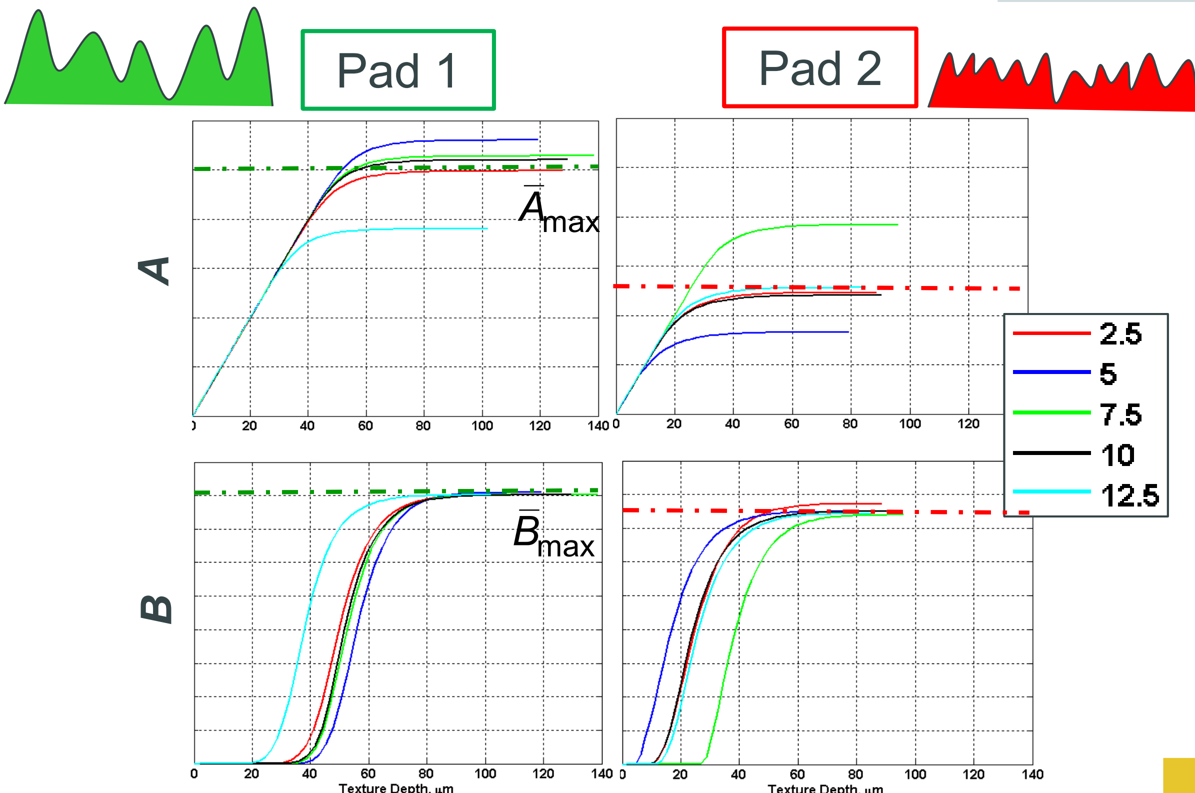


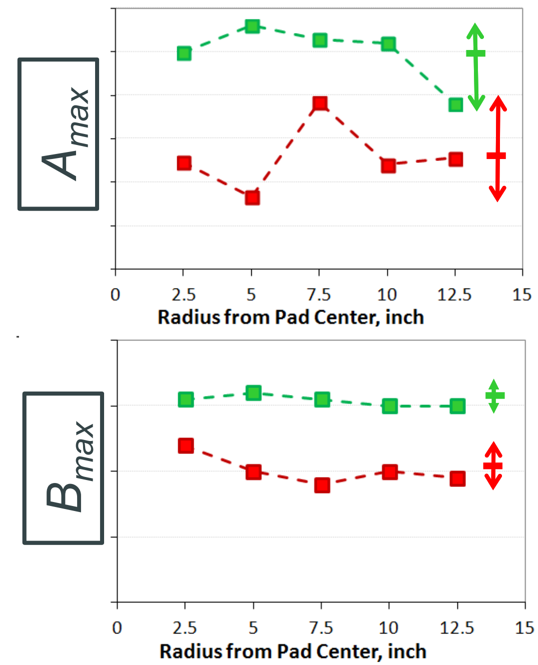
Normalized h_{am}	Pad 1	Pad 2
Avg. h_{am}	2.1 >	1
STDEV of h_{am}	1	1

- Compared to pad 1, pad 2 exhibited smaller texture height above mean (h_{am}) from pad center to edge indicating pad conditioning issue

Texture Parameter *A* and *B*



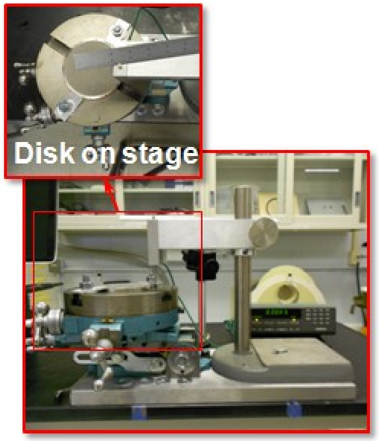




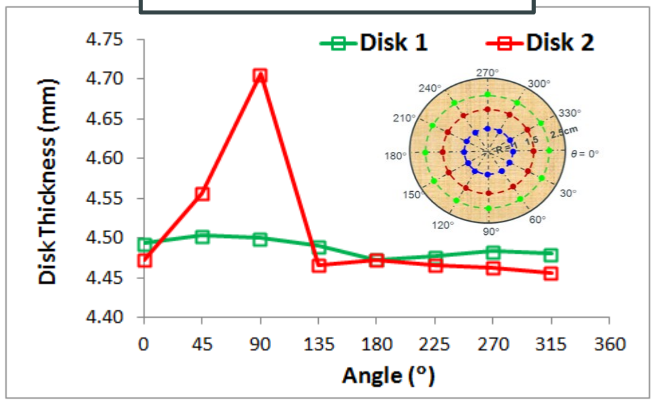
- Compared to pad 1, pad 2 exhibited smaller texture parameters A_{max} and B_{max} although less variation due to insufficient conditioning

Normalized *A*, *B*	Pad 1	Pad 2
Avg. A_{max}	1	> 0.52
STDEV of A_{max}	1	0.86
Avg. B_{max}	1	> 0.93
STDEV of B_{max}	1	2

Disk Flatness and Diamond Wear

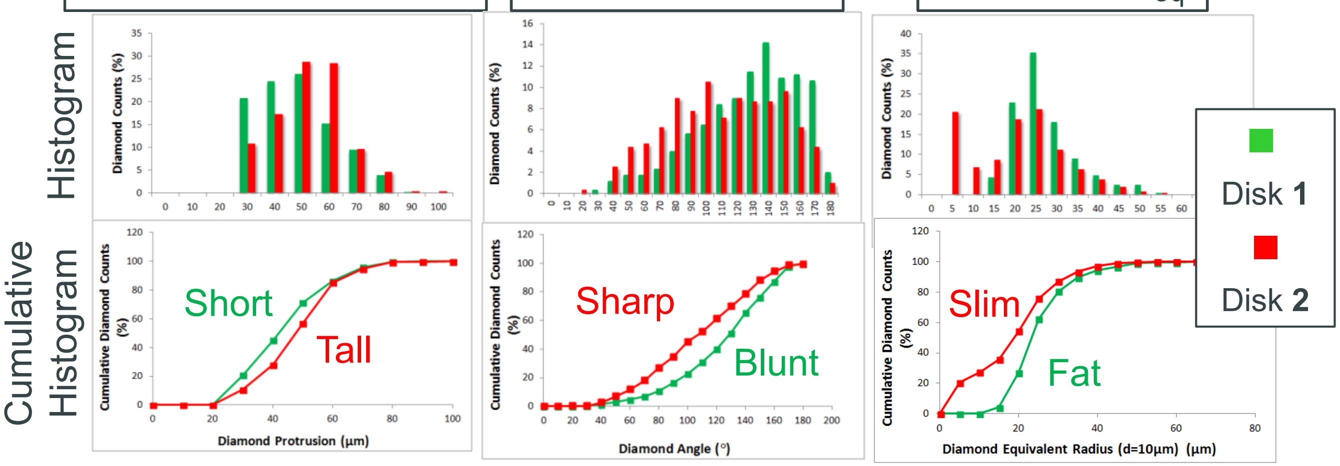


Disk Flatness



Measured by a custom thickness gauge (resolution: 10 μm)

Diamond Protrusion | Diamond Angle | Diamond R_{eq}



- Relative to disk 1, disk 2 exhibited significantly worse base flatness
  - Indicative of root cause of conditioning issue
- Diamond wear analysis was aligned with disk flatness
  - Relative to disk 1, disk 2 exhibited taller, sharper and slimmer diamonds indicating less diamond wear due to worse flatness

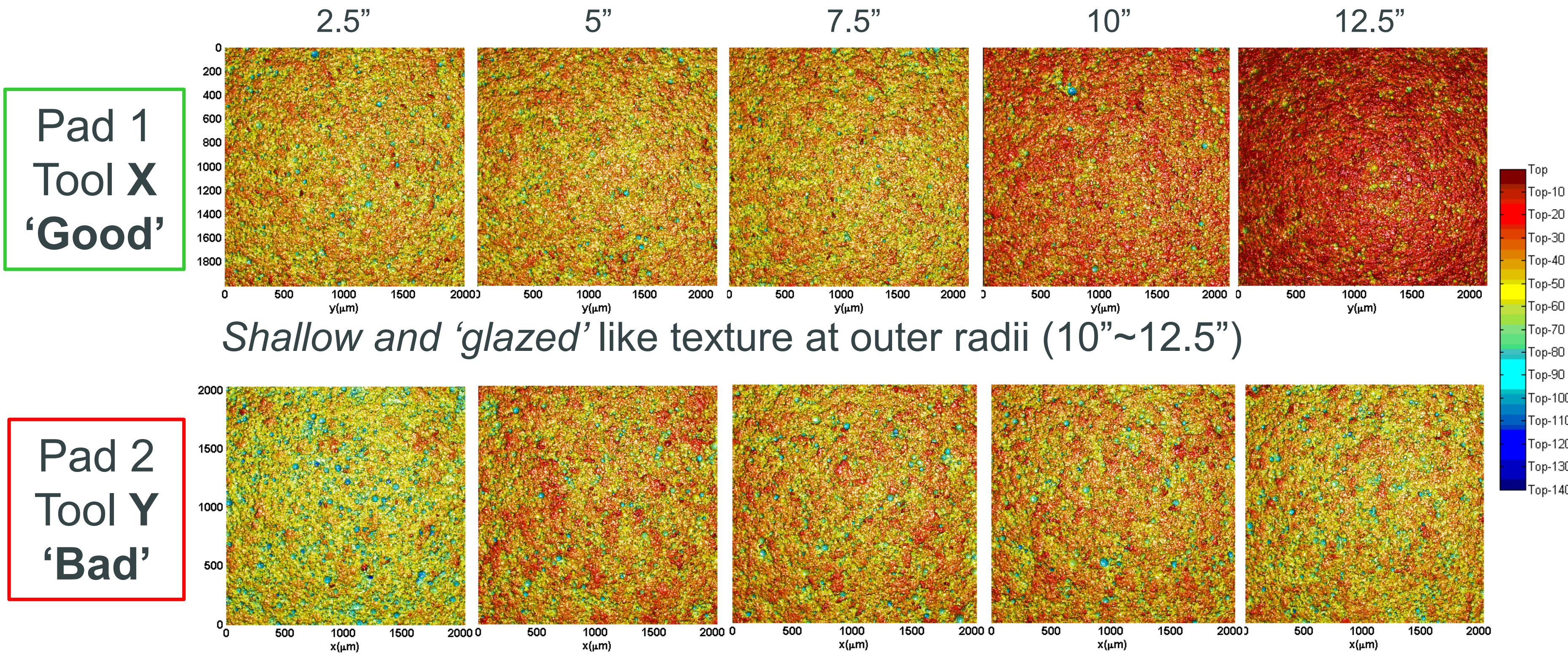
Learning 4

Impact of Polishing Tool – Conditioning System

	Pad	Pad Life	Disk Type	Polishing Tool	Process	Polish Note
1	IC1000™	comparable	same	X	same (STI polish)	***Good***
2				Y		***Bad, Unstable RR***

- Conditioning system (including both hardware and software) difference between polishers can impact pad conditioning and diamond wear consequently polishing performance
- It is important to link specific polishing application to its favorable pad surface texture for process improvement and troubleshooting

Pad Surface Texture (2x2mm^2)



Shallow and ‘glazed’ like texture at outer radii (10”~12.5”)

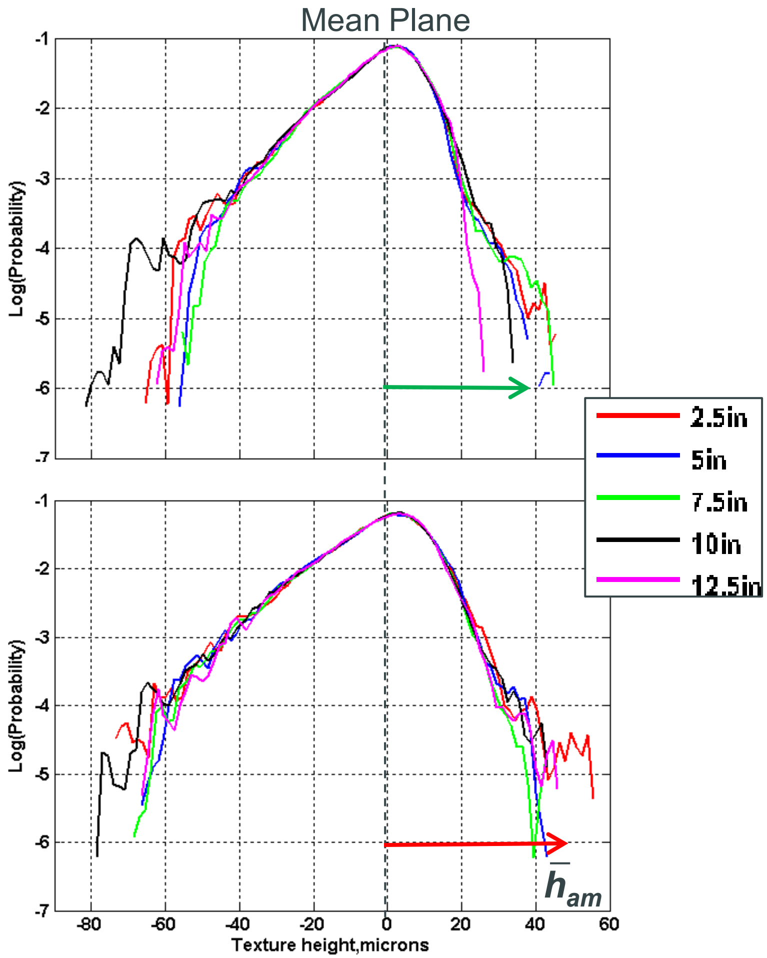
Relatively *deep* texture with less variation from pad center to edge

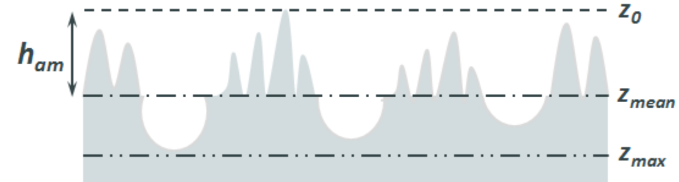
- Difference in pad surface texture across radii can lead to polishing performance difference given other properties same
- Seemingly ‘good’ texture ≠ Favorable texture in the specific application

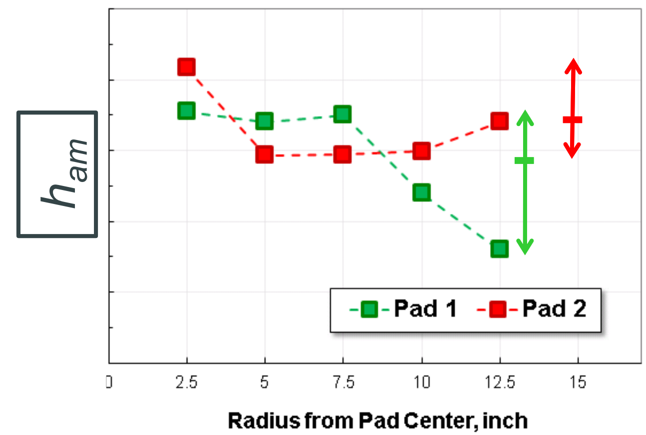
Texture Histogram

Pad **1**
Tool **X**
'Good'

Pad **2**
Tool **Y**
'Bad'



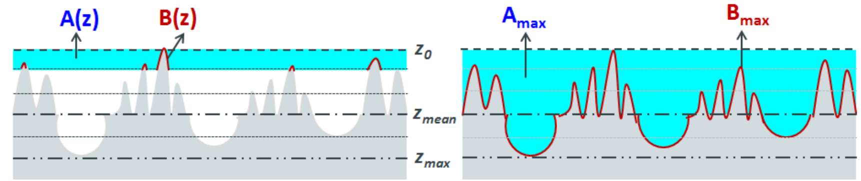


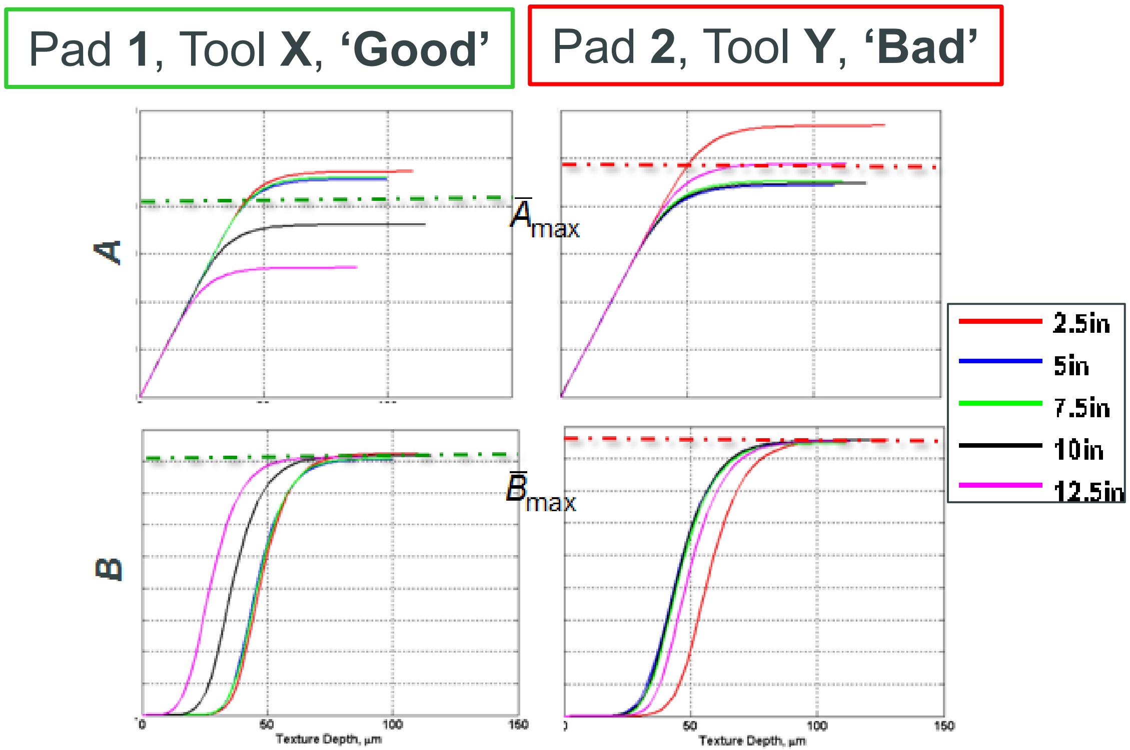


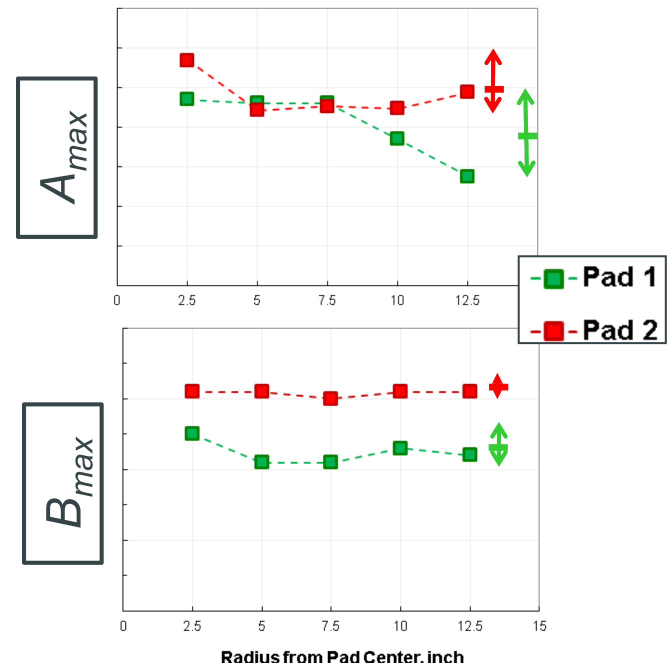
Normalized h_{am}	Pad 1		Pad 2
Avg. h_{am}	1	<	1.1
STDEV of h_{am}	1	>	0.6

- Compared to pad 1, pad 2 exhibited greater texture h_{am} on average and less variation, but unfavorable in the specific application

Texture Parameter A and B







- Similar trend was noted in texture A_{max} and B_{max}
- Such trend was confirmed by characterization of series of pads processed in tool X vs. Y mainly due to different conditioning system

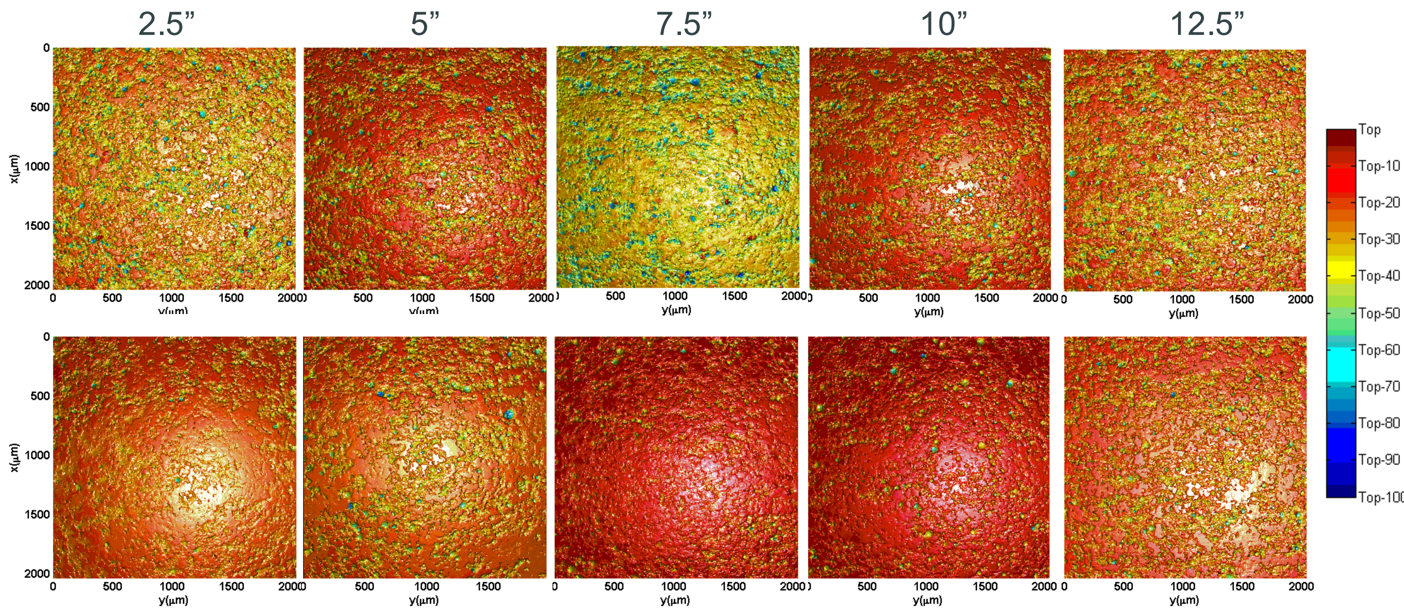
Normalized	Pad 1		Pad 2
Avg. A_{max}	0.85	<	1
STDEV of A_{max}	1.6	>	1
Avg. B_{max}	0.94	<	1
STDEV of B_{max}	4.2	>	1

Case II: Impact of Polisher on Pad Surface Texture

Disk	Disk Type	Pad Material	Polisher	Process	Polish Note
1	same	IC1000™	I	same (STI polish)	***Good***
2			II		***Bad, RR/Scratch issues***

Pad 1
Tool **I**
'Good'

Pad 2
Tool **II**
'Bad'



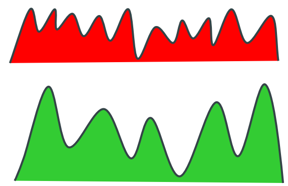
- Relative to pad 1, pad 2 on average exhibited shallower texture, i.e. near center of wafer track
  - consistent with lower pad cut rate and more remaining groove depth note

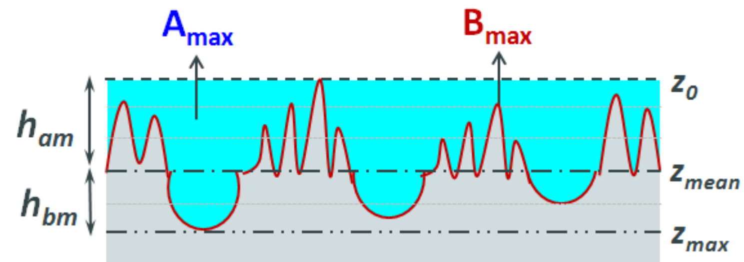
Pad Wear	Pad 1		Pad 2
Avg. Remaining Groove Depth, mil	21.9	<	27.3
Pad Cut Rate (mils/hr)	0.128	>	0.067

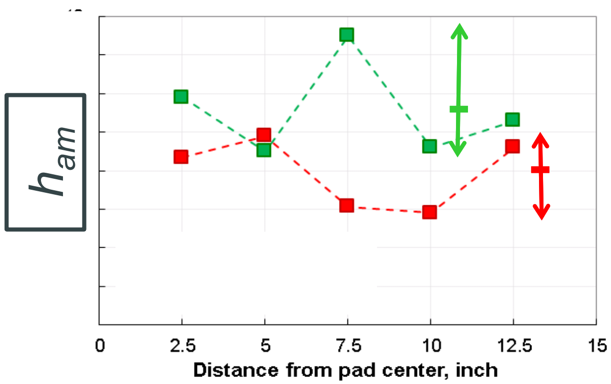
Texture Characteristics

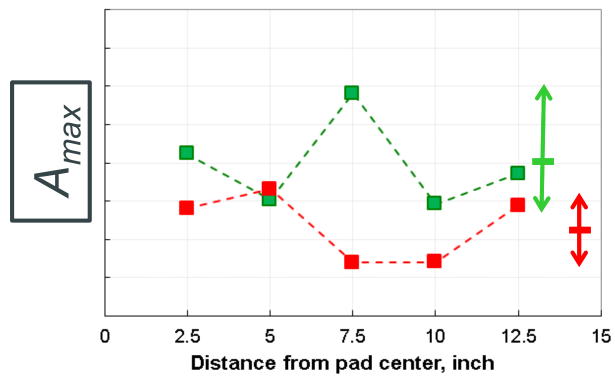
Pad 2, Tool **II**, **‘Bad’**

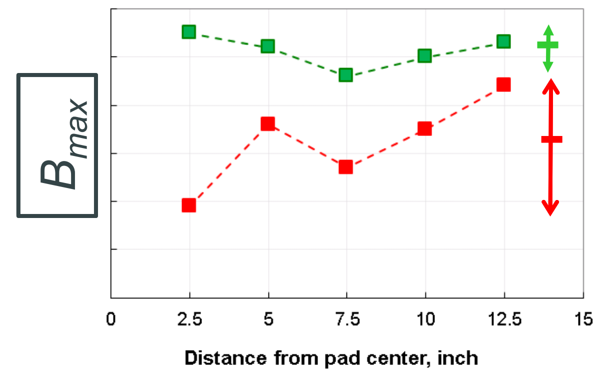
Pad 1, Tool **I**, **‘Good’**







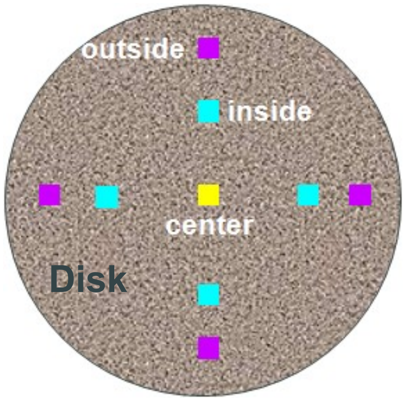




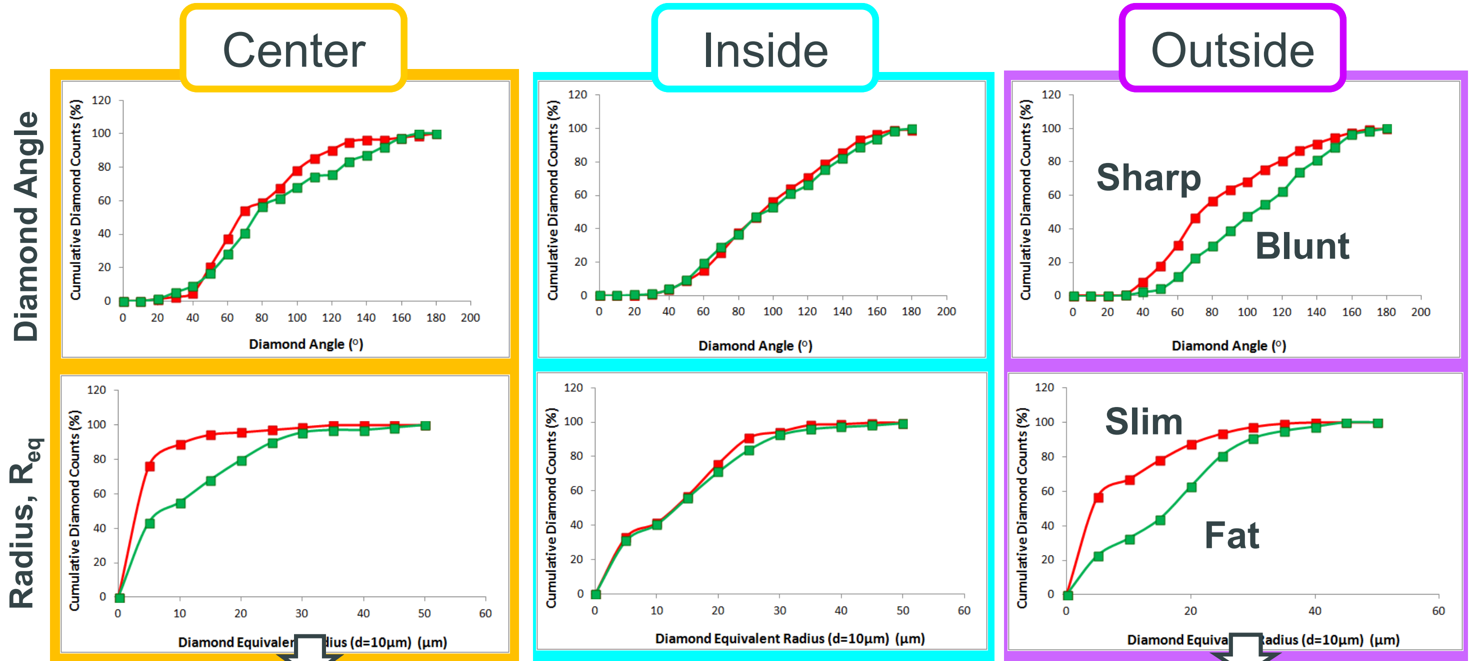
- Compared to pad 1, pad 2 exhibited shallower texture with smaller texture h_{am}, A_{max} and B_{max} on average although less variation, not favored by the specific application
  - Indicative of conditioning issue

Normalized	Pad 1		Pad 2
Avg. h_{am}	1.4	>	1
STDEV of h_{am}	1.2		1
Avg. A_{max}	1.36	>	1
STDEV of A_{max}	1.5		1
Avg. B_{max}	1.14	>	1
STDEV of B_{max}	0.3		1

Diamond Wear

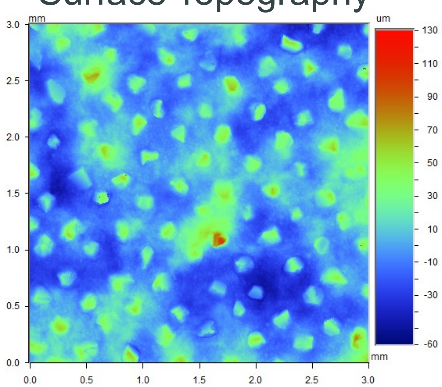


Disk 1, Tool I, 'Good'
Disk 2, Tool II, 'Bad'



Disk 1 (Pad 1/Tool I, 'Good'): **More Diamond Wear**

Surface Topography



- Relative to disk 2, disk 1 exhibited significantly more diamond wear in disk center and outside indicating more active diamonds in conditioning
- Polishing tool difference was the root cause of pad conditioning and polish performance issue

Conclusion

- A characterization method to precisely and statistically quantify CMP pad surface texture is developed
  - A combination of texture characteristic parameters provide an insight into pad conditioning and polishing performance
- Pad surface texture and polishing performance is impacted by disk properties including diamond properties, diamond wear and disk flatness, and polishing tool for given process
- Advanced characterization capabilities are necessary for in-depth understanding of CMP, to provide differentiated CMP consumables and scientific solutions

Thank You

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