Advances in CMP Pad Conditioning

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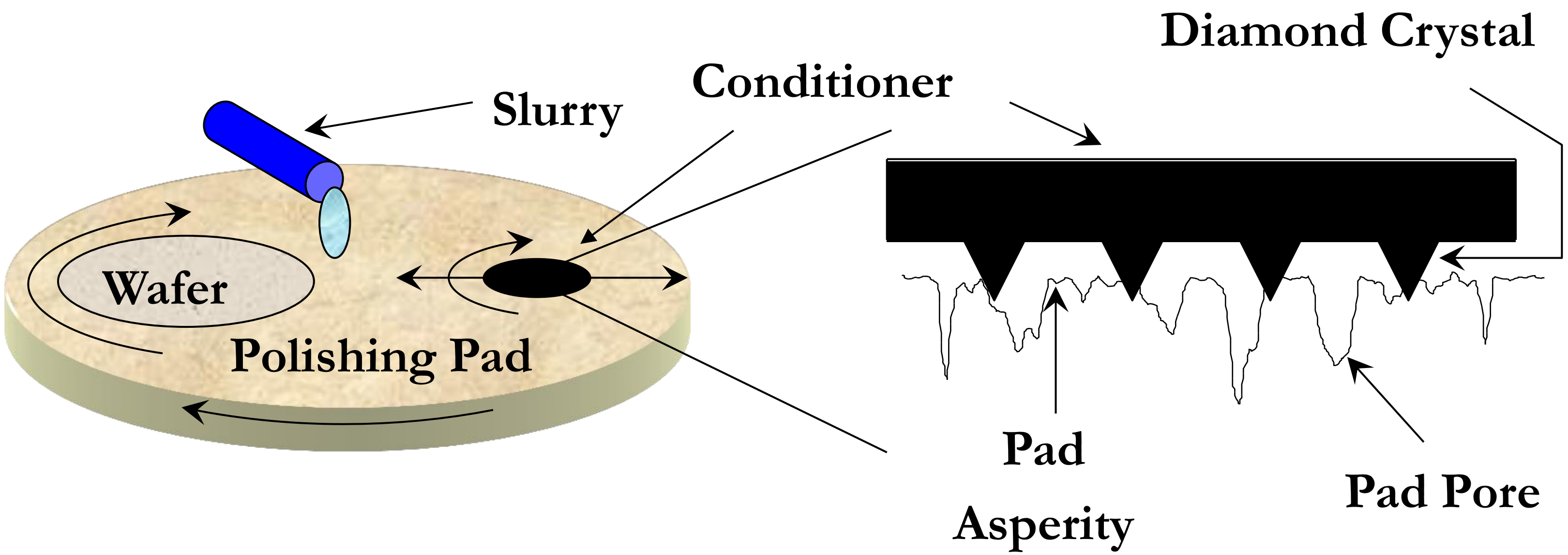
Outline

- Pad Conditioning Background
- The Importance of Conditioning
  - Texture Generation
  - Process Interactions
- The Evolution of Conditioning Technology
- The State of the Art and the Future of Conditioning
- Conclusions

CMP Pad Conditioning Fundamentals

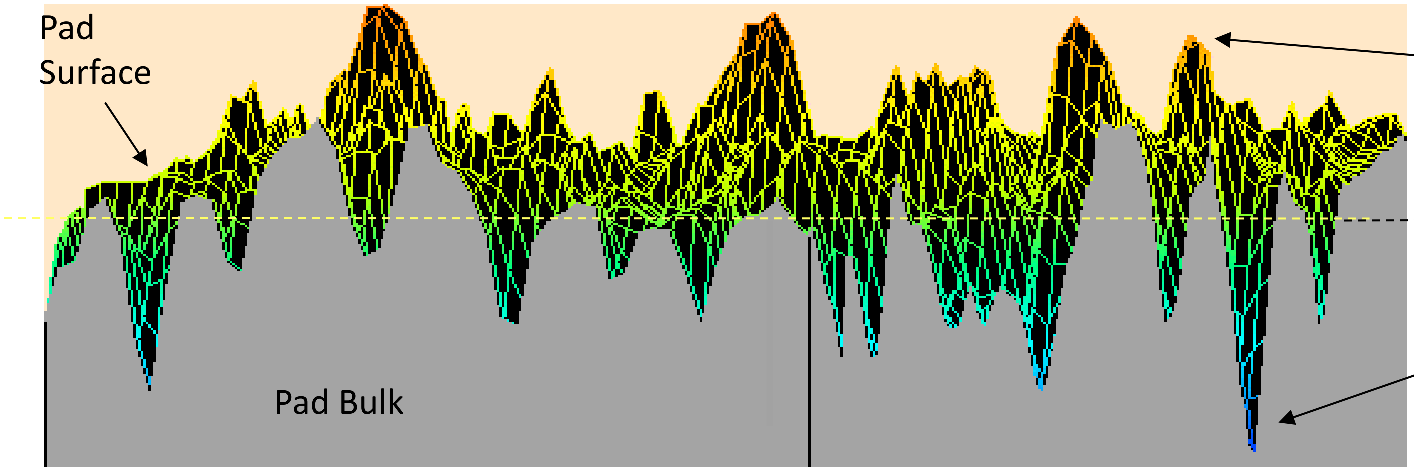


- CMP Pad conditioning is the process of “dressing” the polishing pad with an abrasive medium, typically a diamond abrasive disc
- Conditioning determines the asperity structure of the pad
- Conditioning acts to maintain pad surface stability through the removal of worn surface material and restoration of the intrinsic structure

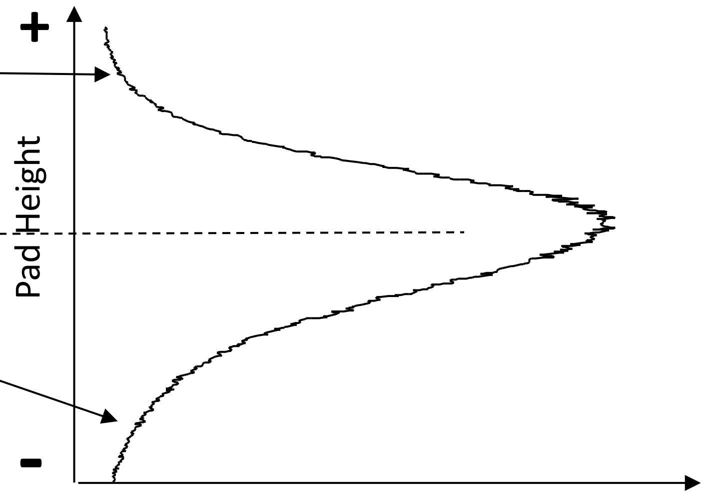
1. A.S. Lawing NCCAVS CMPUG, May 2004.
   Available online at: http://www.avsusergroups.org/cmpug_pdfs/CMPUG_05_2004_Lawing.pdf

Surface Height Probability Distributions

Pad Surface 3-Dimensional Data



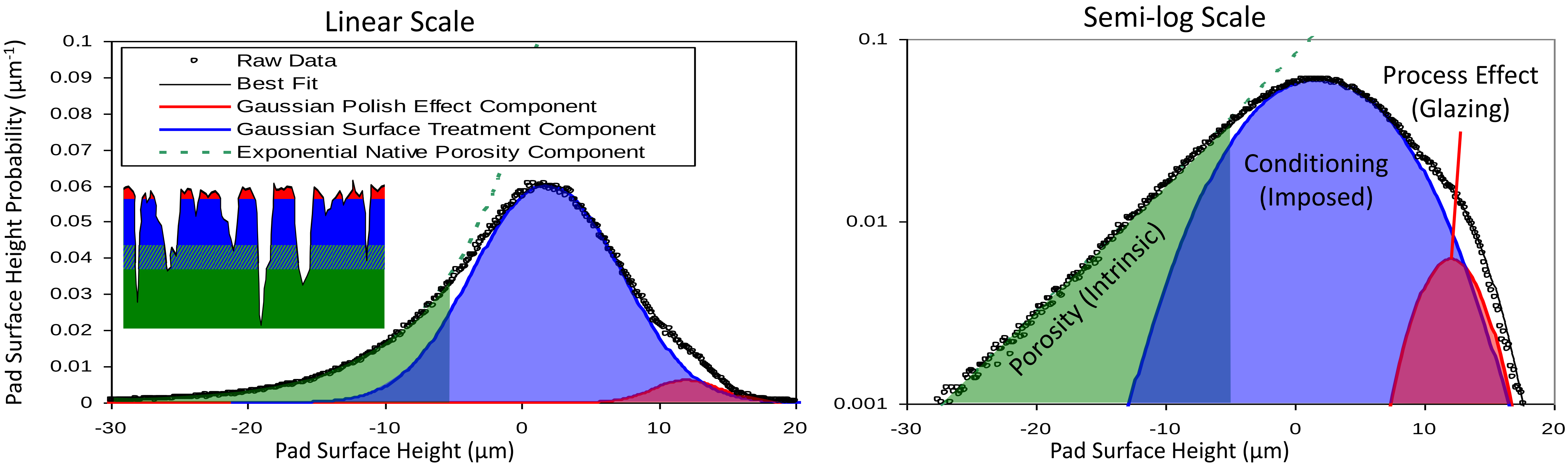
Pad Surface Height Distribution



- Pad texture measured via Vertical Scanning Interferometry
- The pad surface height probability distribution describes how the pad surface is distributed in vertical space
  - The pdf doesn’t contain any information about the lateral distribution of asperities
- Things to keep in mind
  - The “zero level” is arbitrarily defined as the geometric mean of the data set (50% above, 50% below)
  - Area under the pad height pdf = 1

2. Adapted from: A.S. Lawing, Topics in Plasma Science and Thin Film Applications III - in Honor of Herbert H. Sawin
AIChE Conference, Philadelphia, November 17, 2008

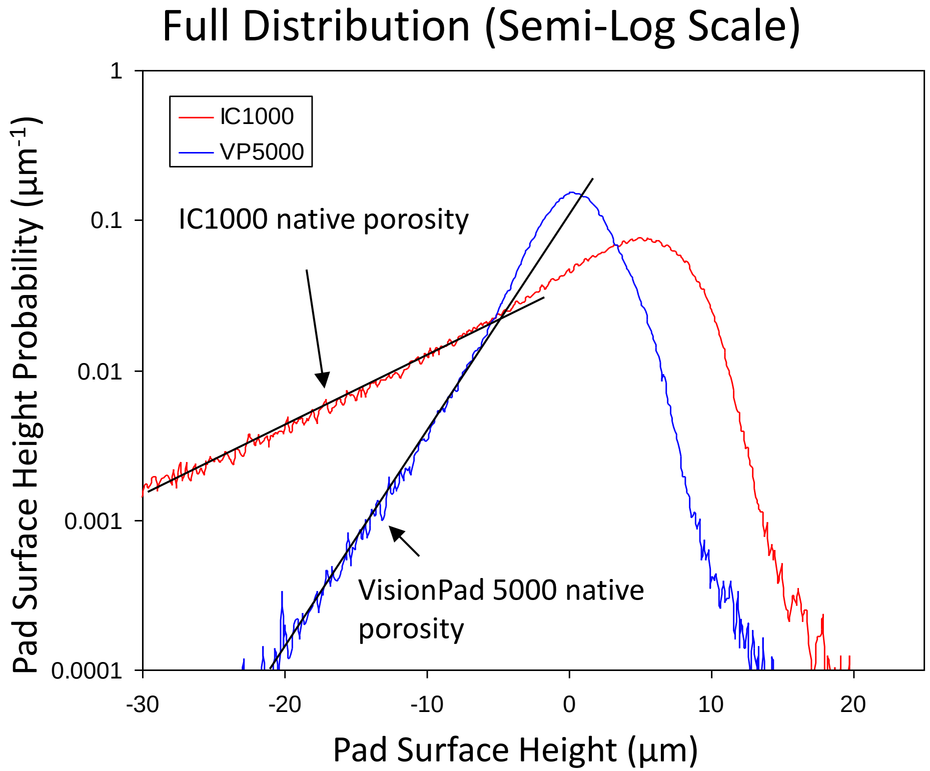
The Three Components of Pad Texture

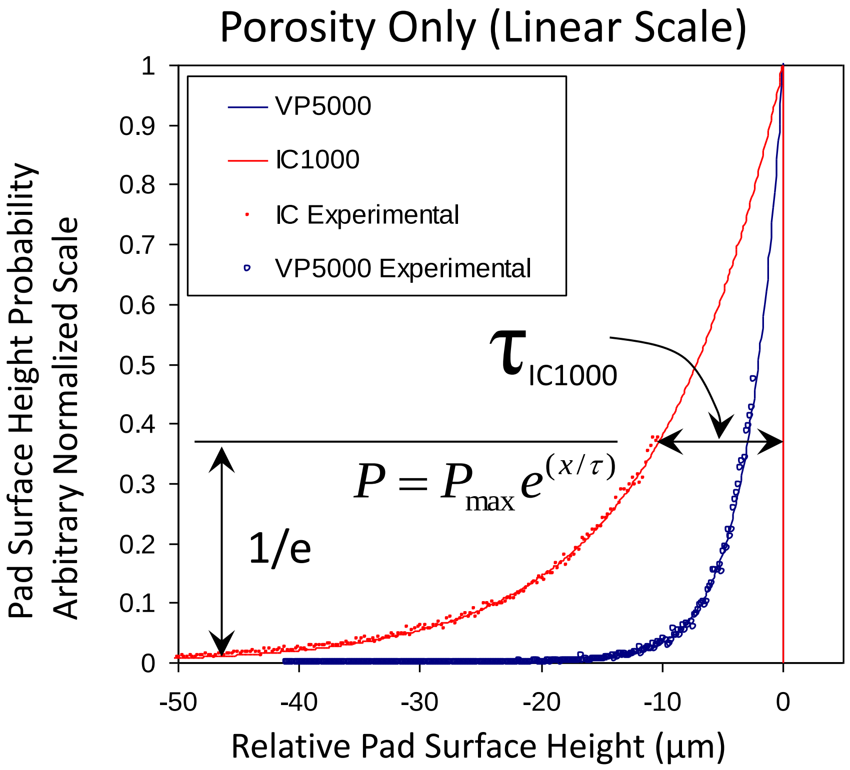


- The most negative part of the distribution is due to pad native porosity and can be modeled as an exponential
- The mid to band of the pad is influenced by the surface treatment
  - Surface treatments include conditioning and skiving processes
- The extreme near surface in this example shows a polish process effect
  - Polish process effects include pad asperity wear (glazing) and debris accumulation
  - Polish process effects are not always observed

3. Adapted from: A.S. Lawing, and Chris Juras, ICPT 2007, Dresden, Germany

Pad Porosity



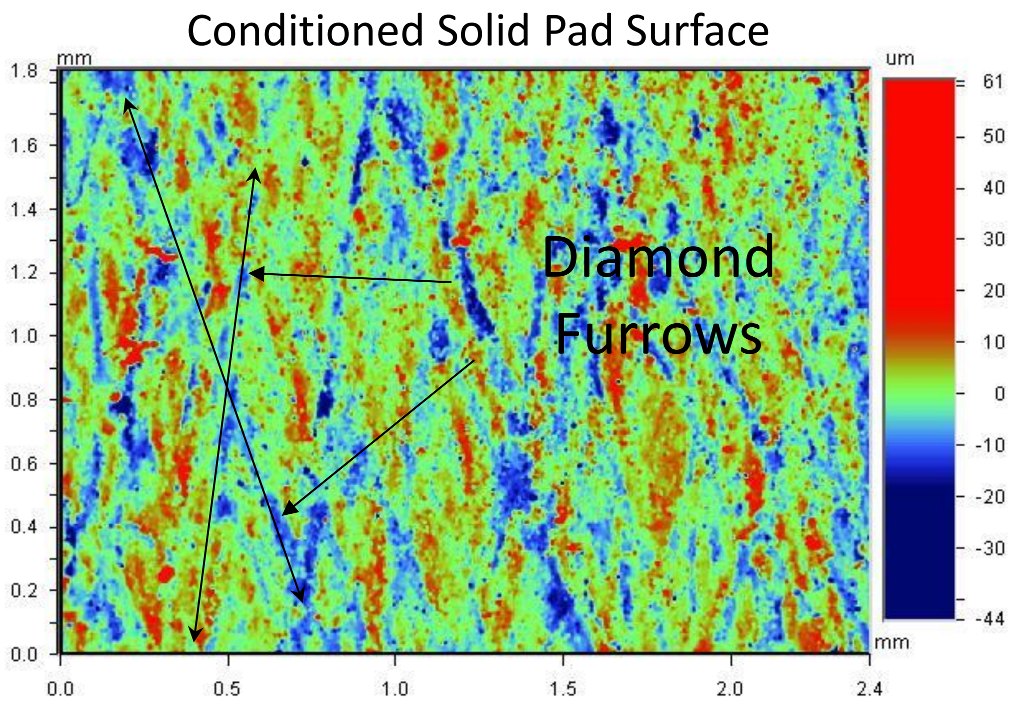


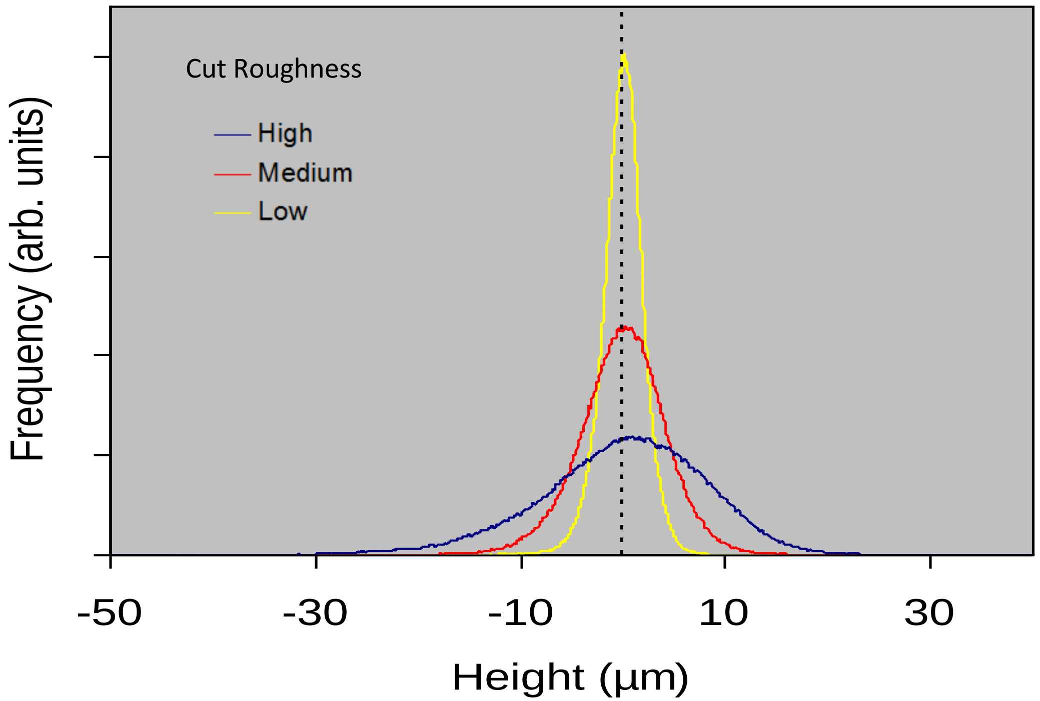
The natural porosity of a porous pad can be modeled as an exponential distribution

- Pad manufacturers have expanded their offerings in terms of available pore structures
- Materials with different pore structures require conditioning tuned to their specific native porosity
- Incompatible conditioning results in a disruption or masking of the native porosity of the material

3. Adapted from: A.S. Lawing, and Chris Juras, ICPT 2007, Dresden, Germany

Pad Conditioning

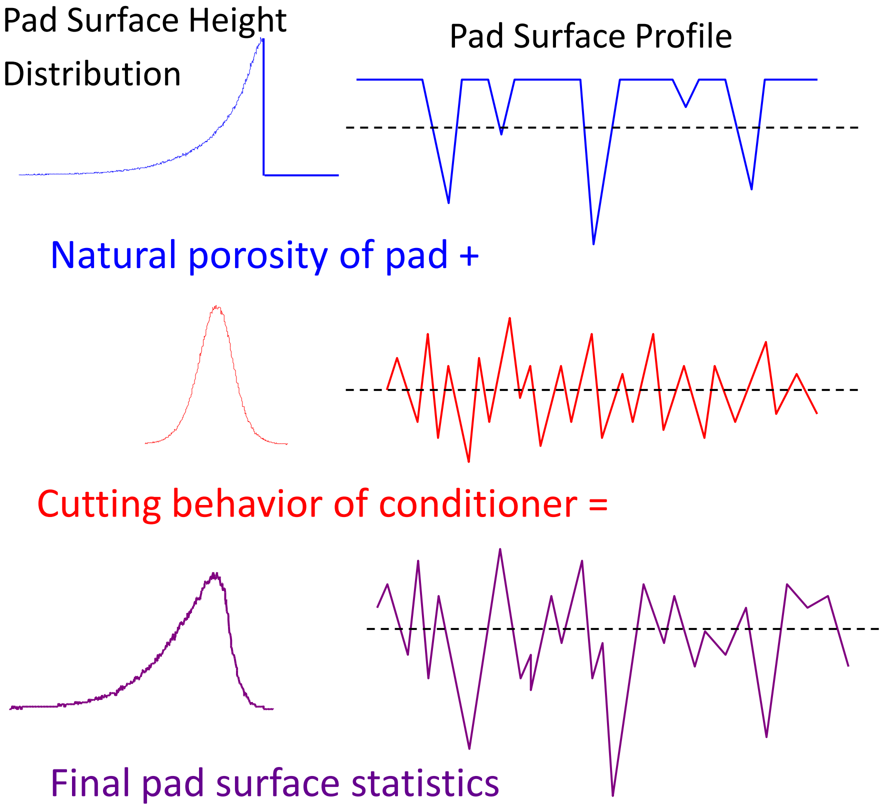


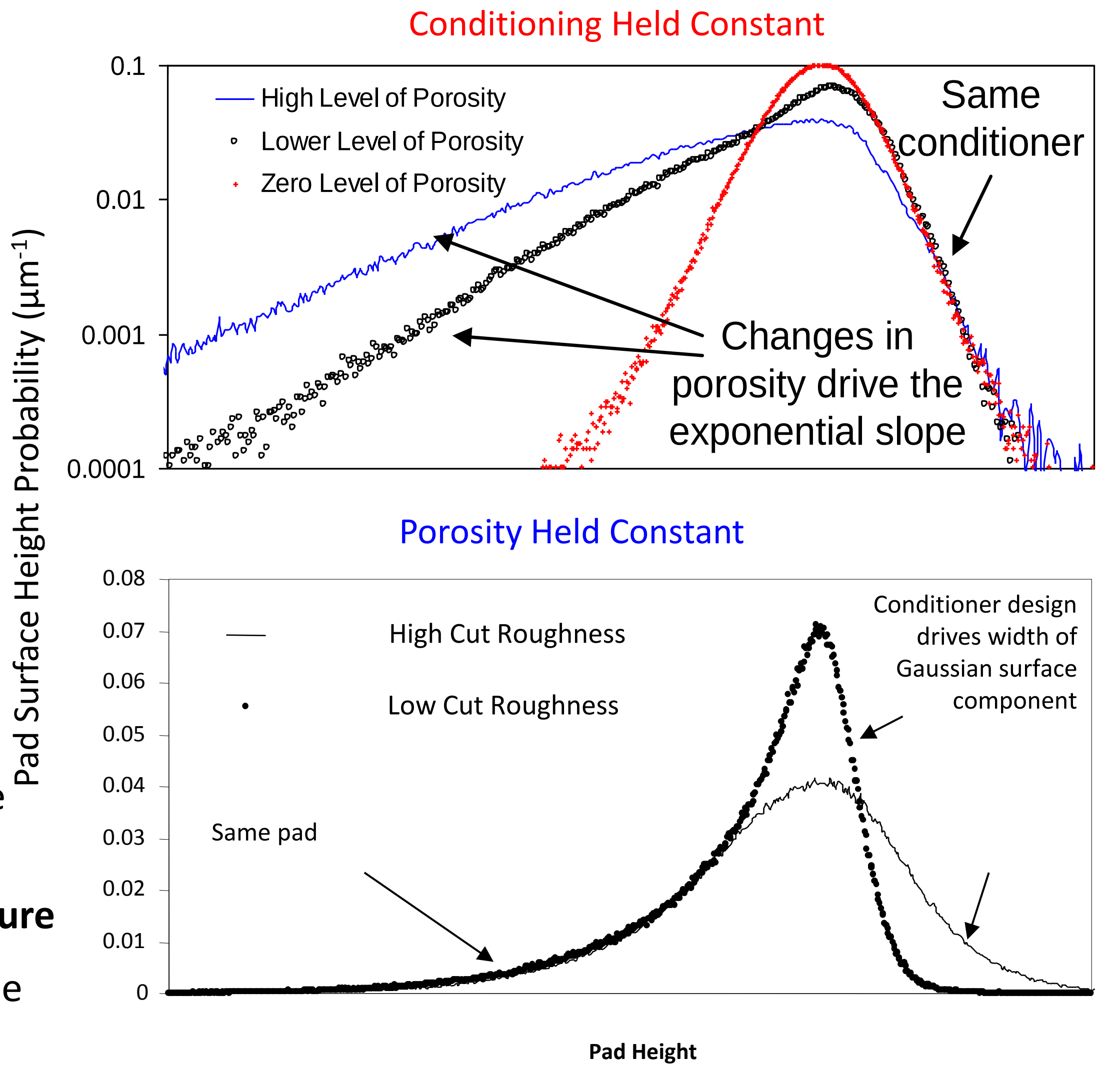


- In the absence of "built in" porosity, the conditioner alone determines pad surface texture
- Conditioner design variables determine the nature of the individual furrows which build up to form the pad texture
- This example shows two different conditioner designs which impart a dramatically different surface roughness to a solid pad

1. A.S. Lawing NCCAVS CMPUG, May 2004.
Available online at: http://www.avsusergroups.org/cmpug_pdfs/CMPUG_05_2004_Lawing.pdf

Pad Porosity + Pad Conditioning

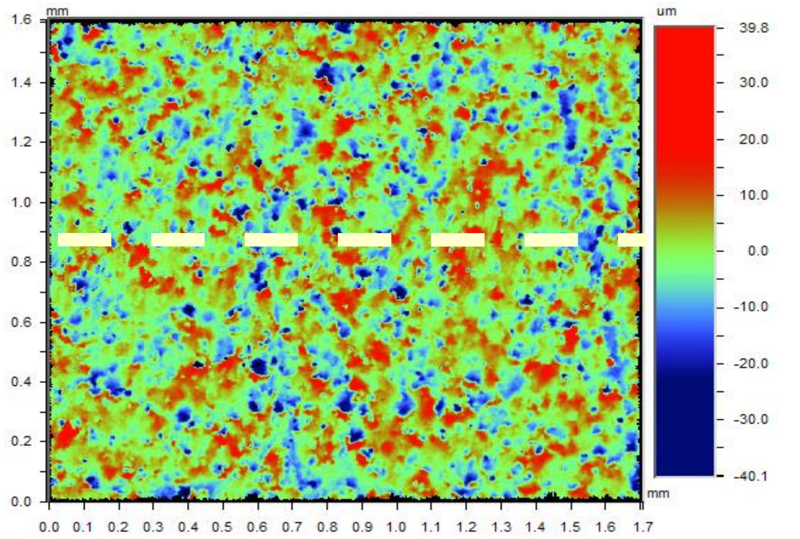




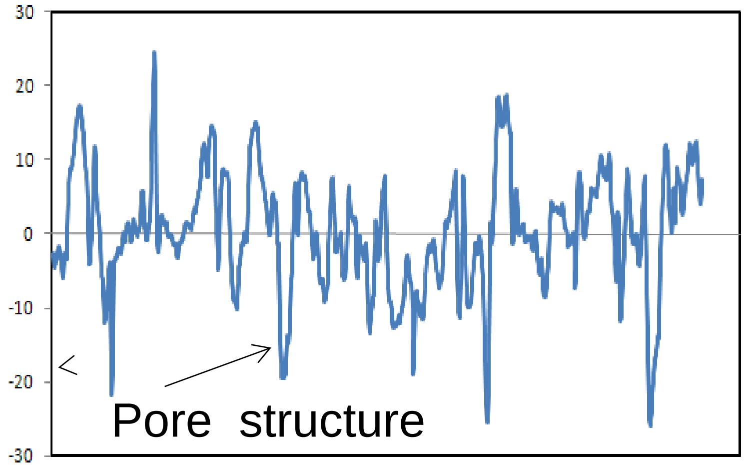
- Final pad surface is the product of the inherent pad texture (**porosity**) and the conditioner cutting characteristic (**near surface roughness**)
- Each pad-conditioner combination will have a **unique (intrinsic) surface structure**
- Cut rate, cutting characteristics and the resulting near surface roughness can be **driven over a large range through conditioner design**

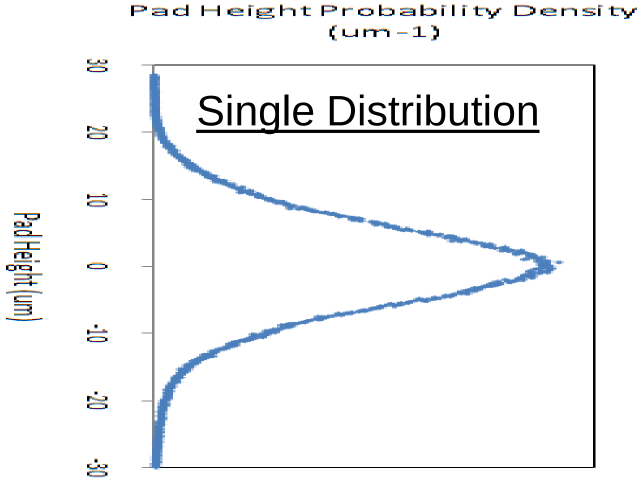
4. A.S. Lawing NCCAVS CMPUG, April 2007.
Available online at: http://www.avsusergroups.org/cmpug_pdfs/CMP2007_4_Lawing.pdf

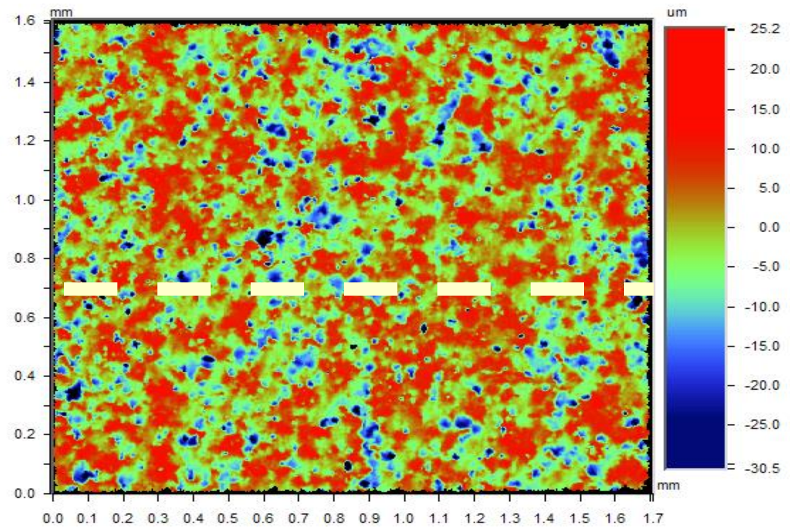
Pad Glazing



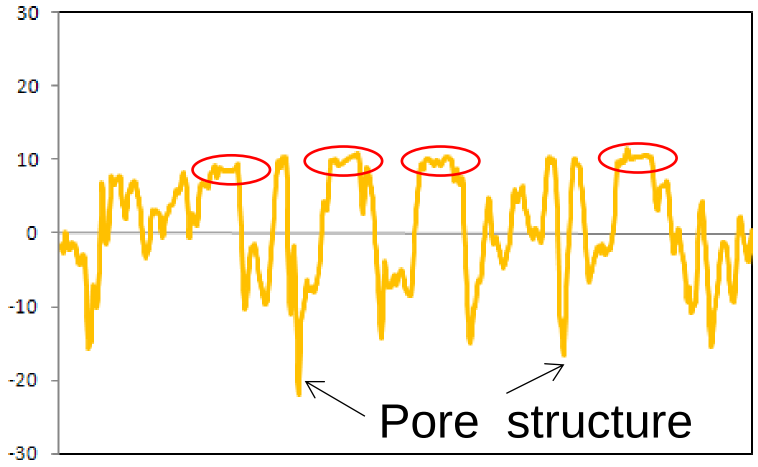
Fully Conditioned Pad Surface

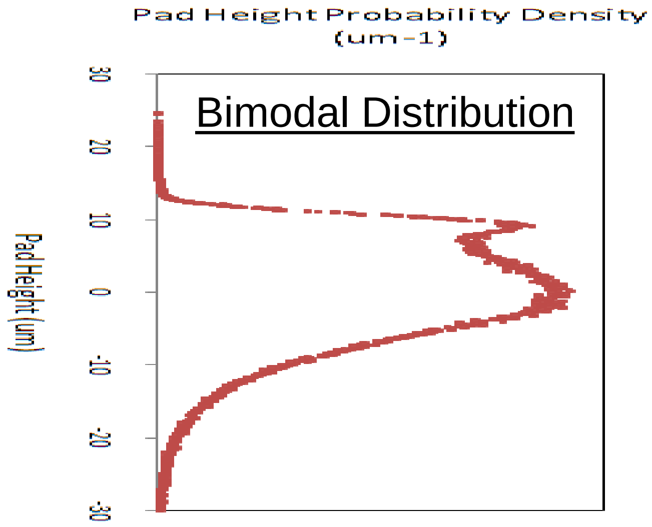






Glazed Pad Surface





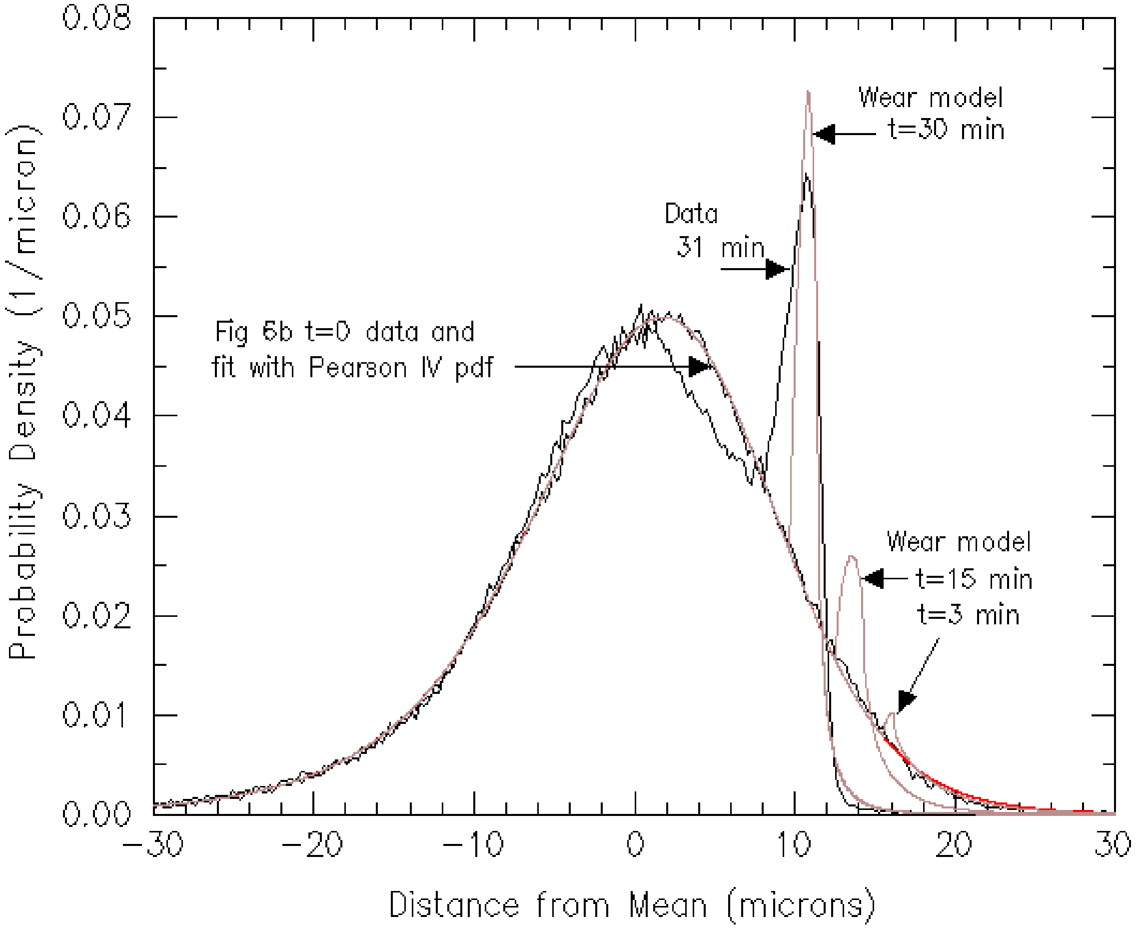
5. K. Arun Reddy, A. Scott Lawing, G. Scott Koons, Yi Guo, Z. Liu, ICPT 2010, Phoenix, AZ, Nov 16, 2010

Pad Glazing

Wear of the pad surface by the slurry & wafer erodes tall asperities into shorter ones, creating a moving secondary peak in the surface roughness pdf near the separation distance.

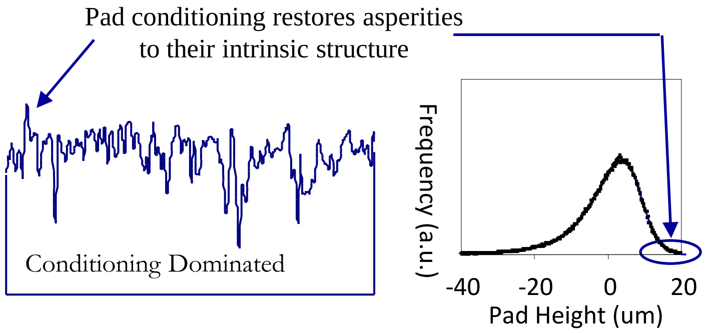
The wear model proposed by Borucki predicts the general features seen in the experimental data of Lawing and others:

- Secondary peak moves to the left and increases in height with time.
- The tail to the right of the secondary peak becomes steeper with time.

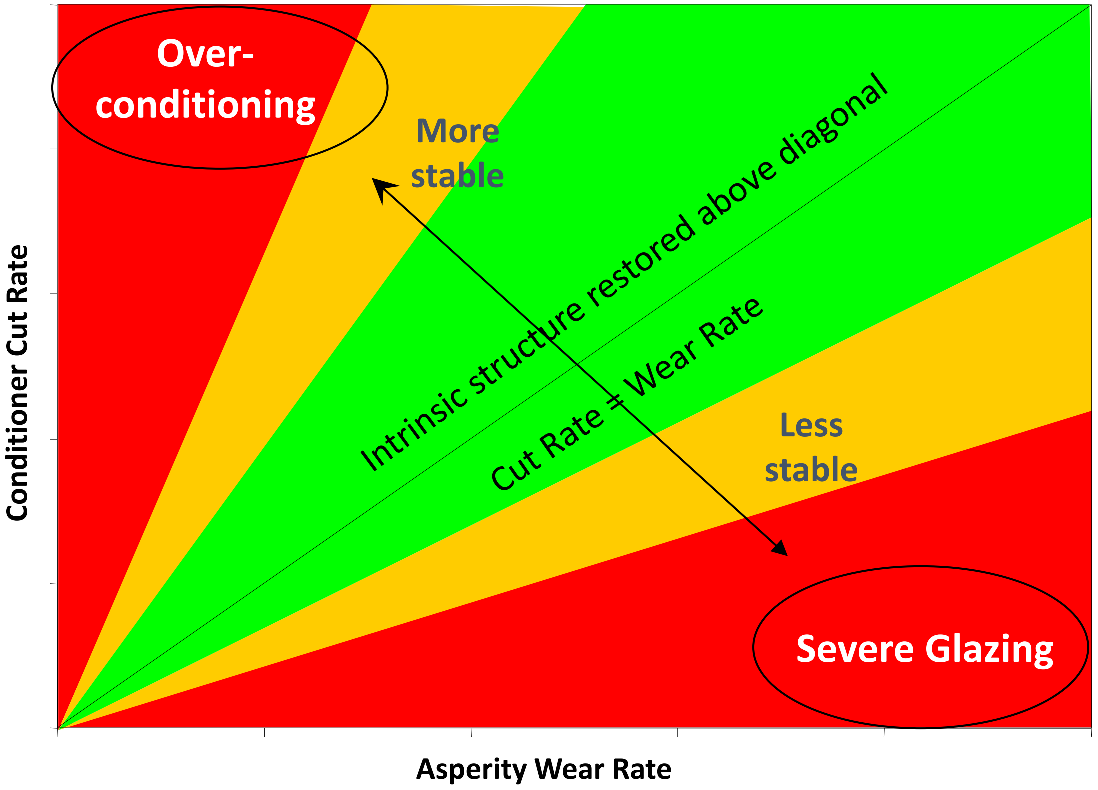


6. L. Borucki, "Mathematical Modeling of Polish Rate Decay in Chemical-Mechanical Polishing" Journal of Engineering Mathematics 43: 105-114, 2002

Pad Wear vs. Asperity Wear (Glazing)

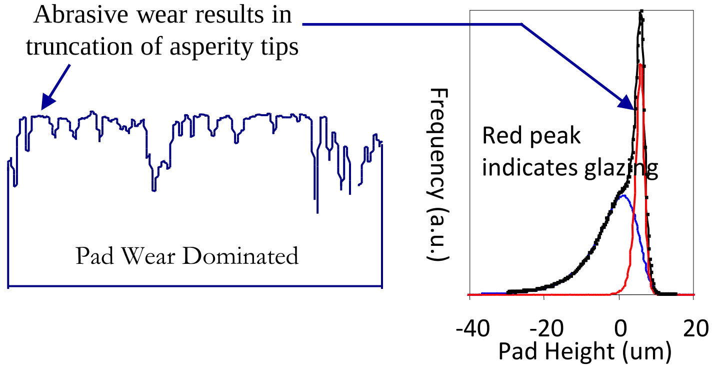


Conditioner cut rate is a function of the conditioner design and pad properties as well as process and consumable conditions



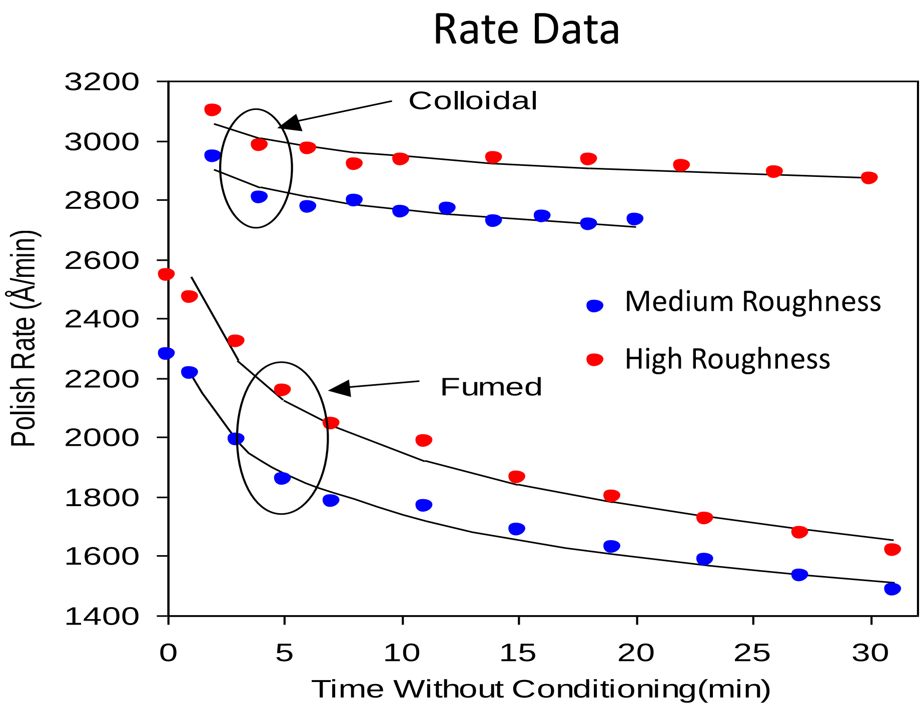
Pad surface structure is determined by the balance between the competing effects of asperity wear due to pad-wafer contact and pad surface restoration due to conditioning

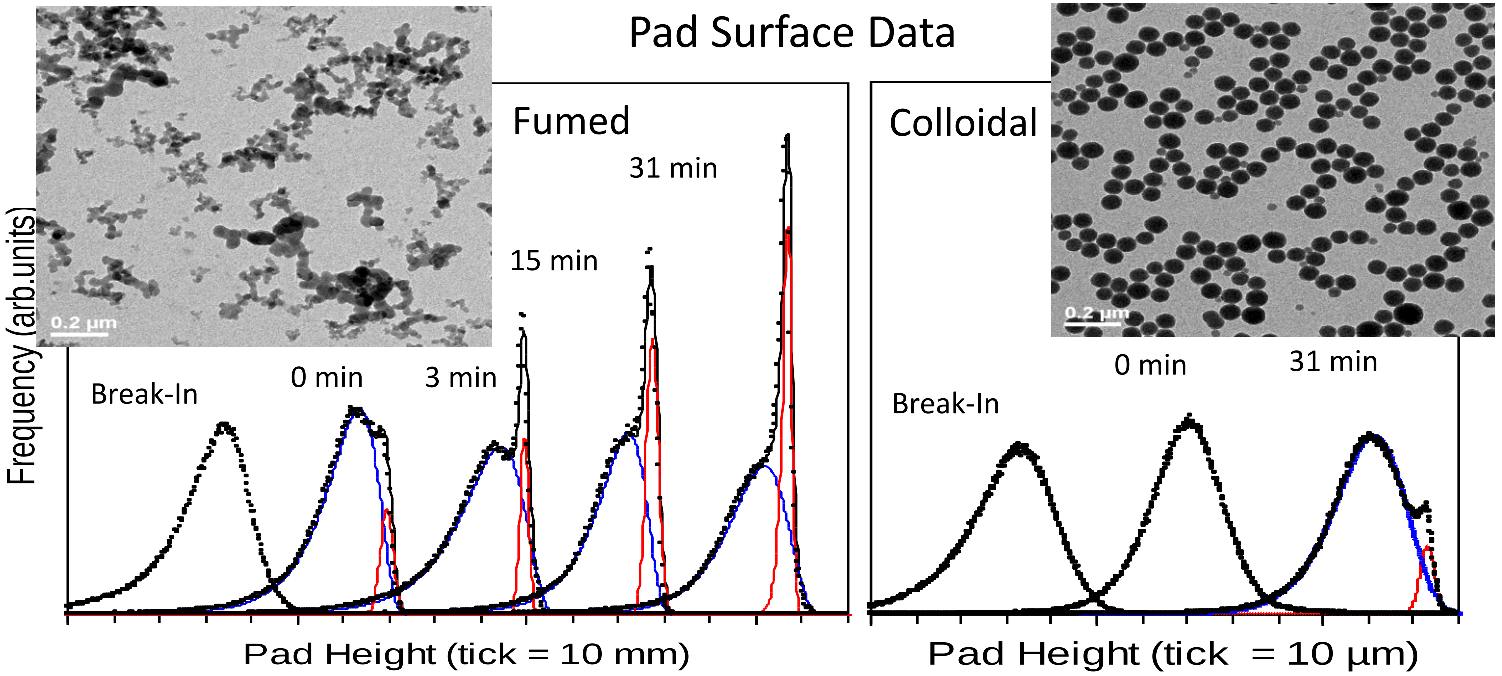
The asperity wear rate is a function of pad properties as well as process and consumable conditions



1. Adapted from A.S. Lawing NCCAVS CMPUG, May 2004.
Available online at: http://www.avsusergroups.org/cmpug_pdfs/CMPUG_05_2004_Lawing.pdf

Slurry/Particle Type Effects - Ex Situ Rate Decay and Glazing





- Typical "logarithmic" decay of rate after conditioning is suspended
- Increase in asperity wear with time corresponds to decrease in polish rate
- Colloidal slurries induce less significant asperity wear and result in less significant rate decay
- Conditioning sets initial rate but has little influence after conditioning is suspended

1. Adapted from: A.S. Lawing NCCAVS CMPUG, May 2004.
   Available online at: http://www.avsusergroups.org/cmpug_pdfs/CMPUG_05_2004_Lawing.pdf

Asperity Population and Planarization Performance

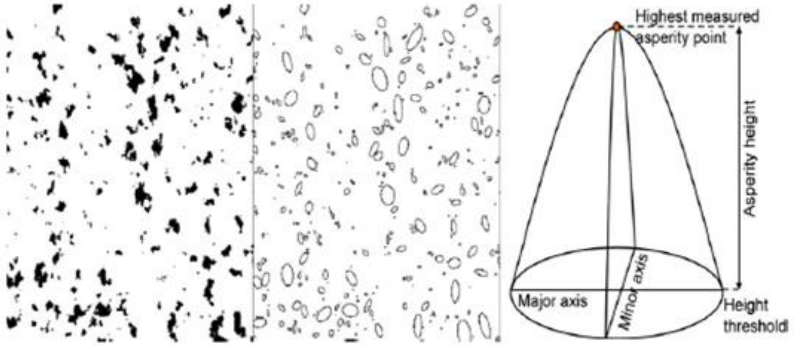


Fig. 4. Left: Asperities found on the pad at 14 μm height threshold. Right: Asperities contours approximated by ellipses.

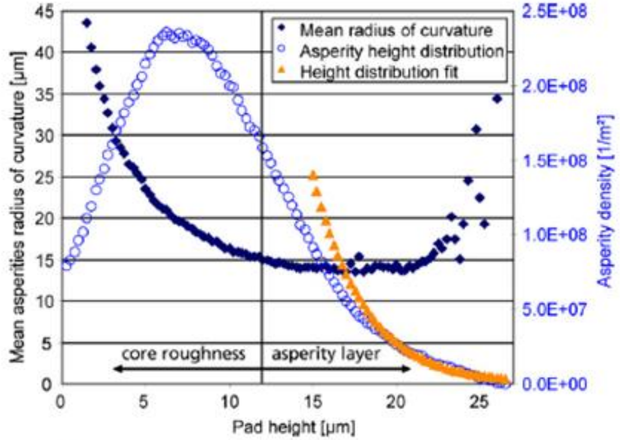


Fig. 5. Real height distribution and mean radius of curvature of the asperities as a function of the pad height on which they are measured.

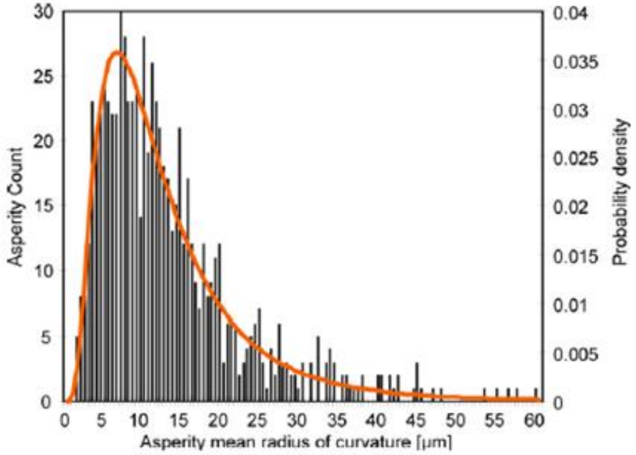
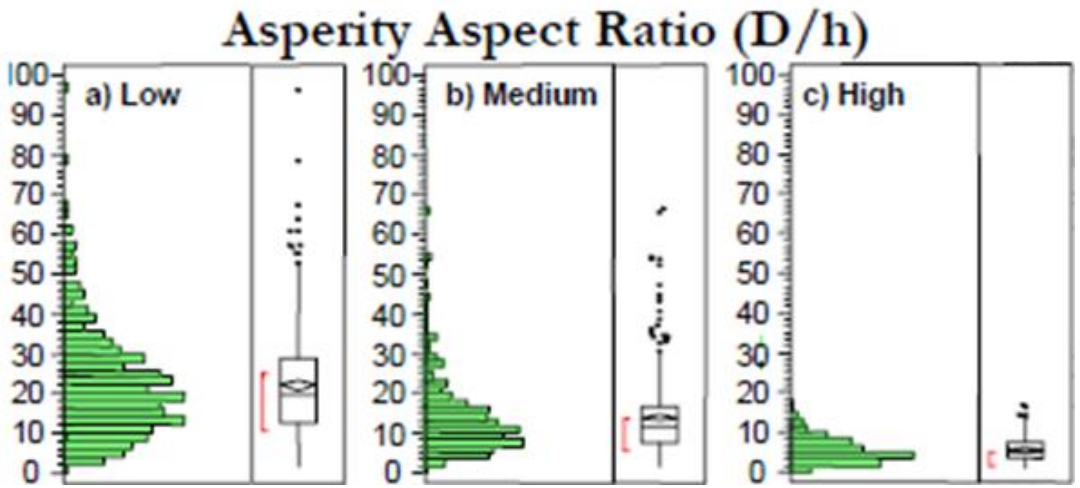


Fig. 6. Asperities radius of curvature distribution measured on the pad surface.

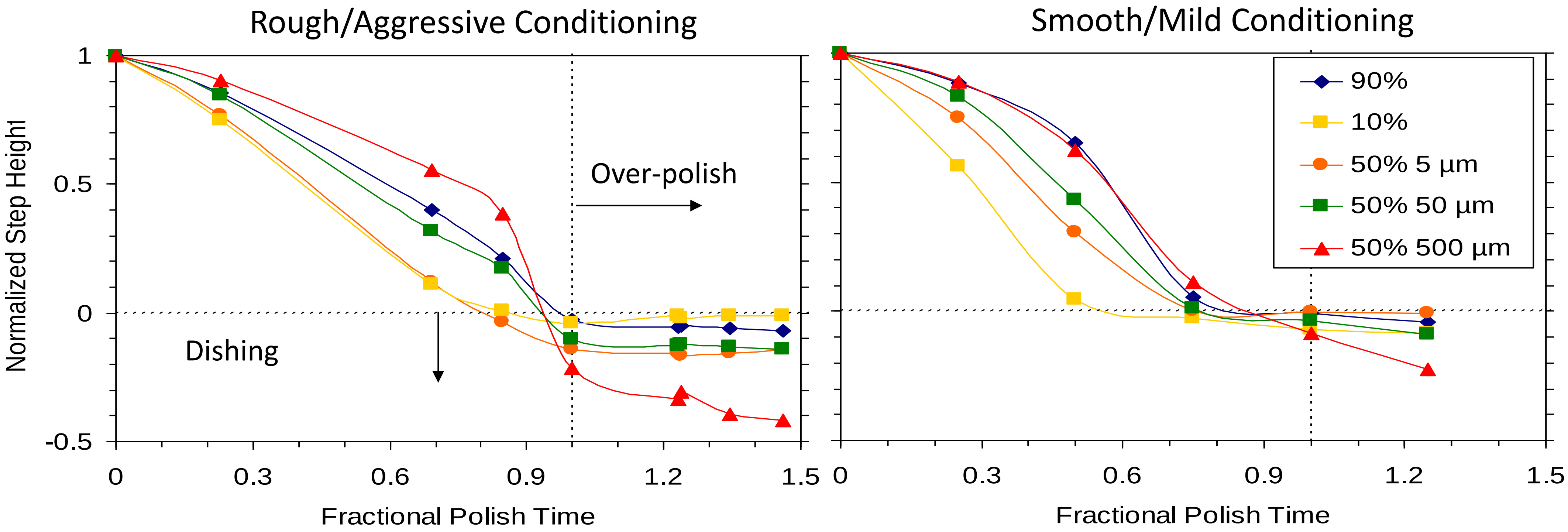
7. Vasiliev, et al., Microelectronic Engineering 104 (2013) P. 51



1. A.S. Lawing NCCAVS CMPUG, May 2004.
Available online at: http://www.avsusergroups.org/cmpug_pdfs/CMPUG_05_2004_Lawing.pdf

- Conditioner cutting characteristics directly affect the pad asperity distribution
- The pad asperity distribution has a direct impact on the interaction of the pad with patterned features

Conditioning and Dishing



- Milder conditioning/smoother surface results in less dishing
  - More truncated asperity structure penetrates less deeply into low lying areas
- In the same way, smoother surfaces are more efficient at removing topography

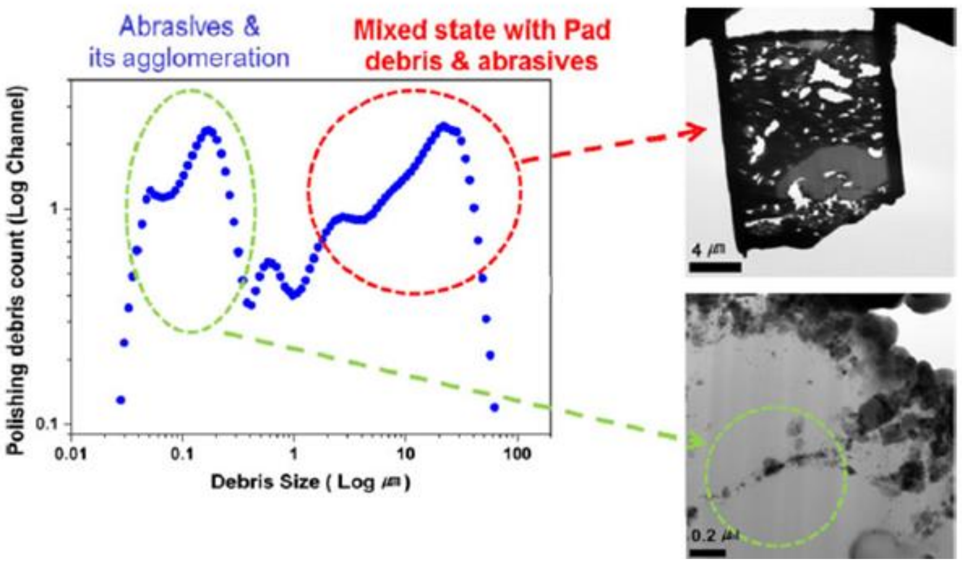
8. A.S. Lawing NCCAVS CMPUG, June 2005.
Available online at: http://www.avsusergroups.org/cmpug_pdfs/CMPUG_2005_06_Lawing.pdf

Conditioning, Debris Generation and Defectivity

Table I. Conditioners designed to obtain various pad surface roughnesses and pad debris sizes

Conditioner ID	1	2	3	4	5	6	7	8	9	10
Diamond size (μm)	130	130	130	165	165	165	225	225	225	225
Conditioner down force (lbf)	3	3	6	3	3	6	3	3	6	9
Shape (S, sharp; M, medium; B, blocky)	S	M	M	S	M	M	S	M	M	B
Distance between diamonds (μm)	315	450	650	315	450	650	315	450	650	650
Mode size of pad debris (μm)	16.6	20.8	22.8	22.9	22.9	24	26.7	27	27.7	29.2

Mode size of pad debris is the average of three measurements for each condition.



9. Yang, et al., Journal of Electronic Materials, Vol 42, No 1 2013 p. 98

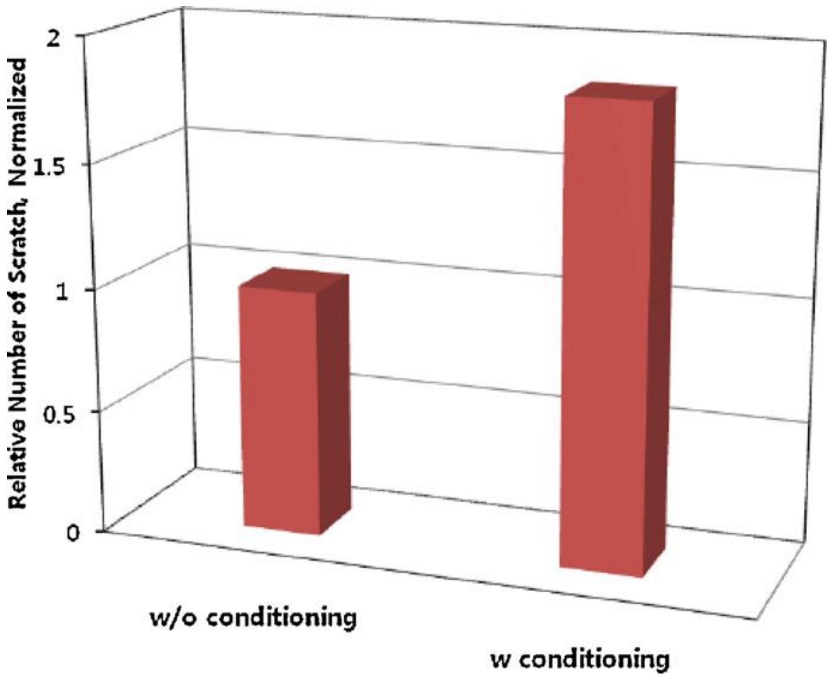
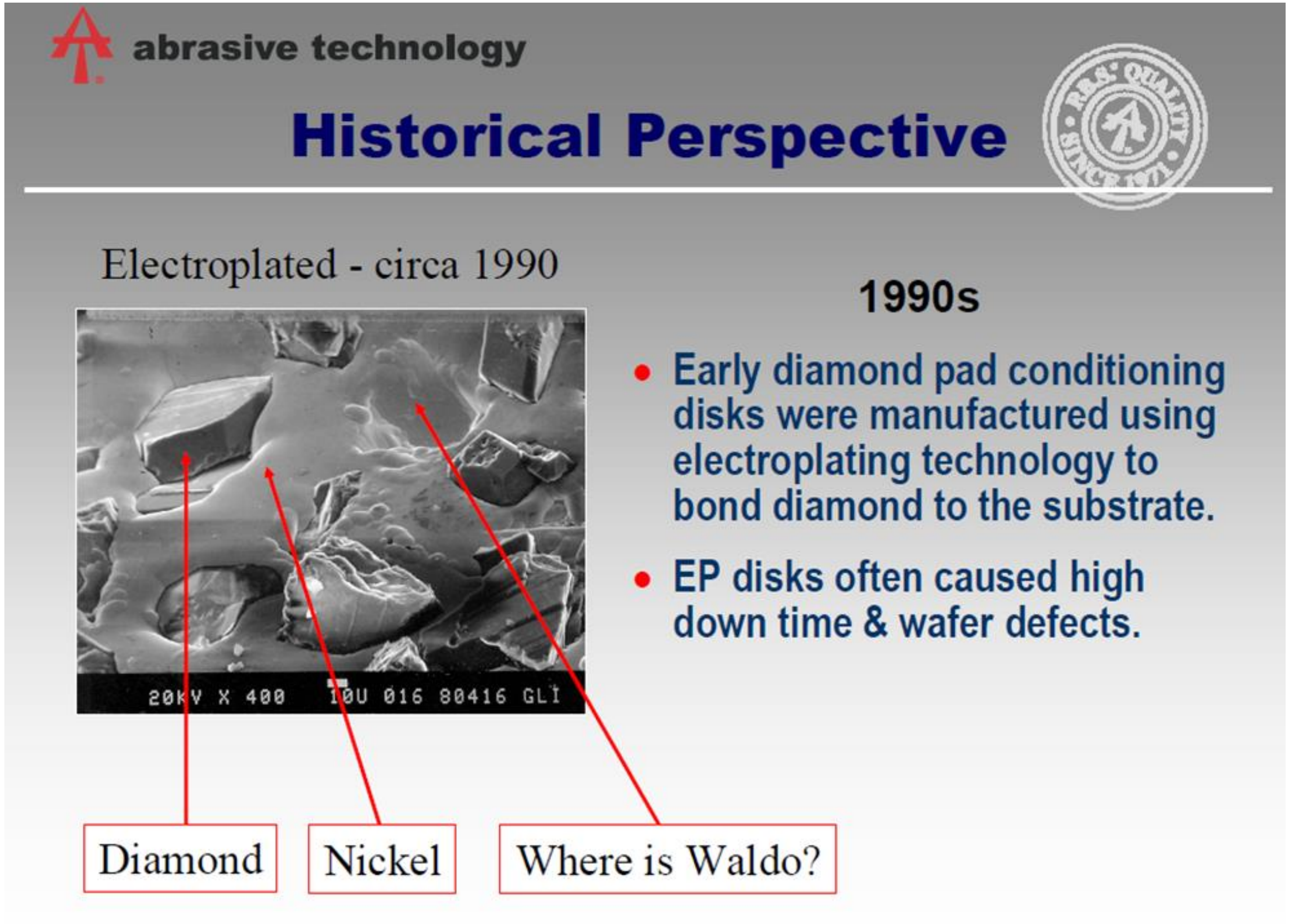


Fig. 3. The relative number of scratches according to the conditioning.

3. Sung, et al., Applied Surface Science, 2058 (2012) p. 8300

- The debris generated by conditioning is a significant contributor to defectivity
- This may be the single most important driver for refining the behavior of conditioners at the level of individual cutting points

Early Conditioning Designs



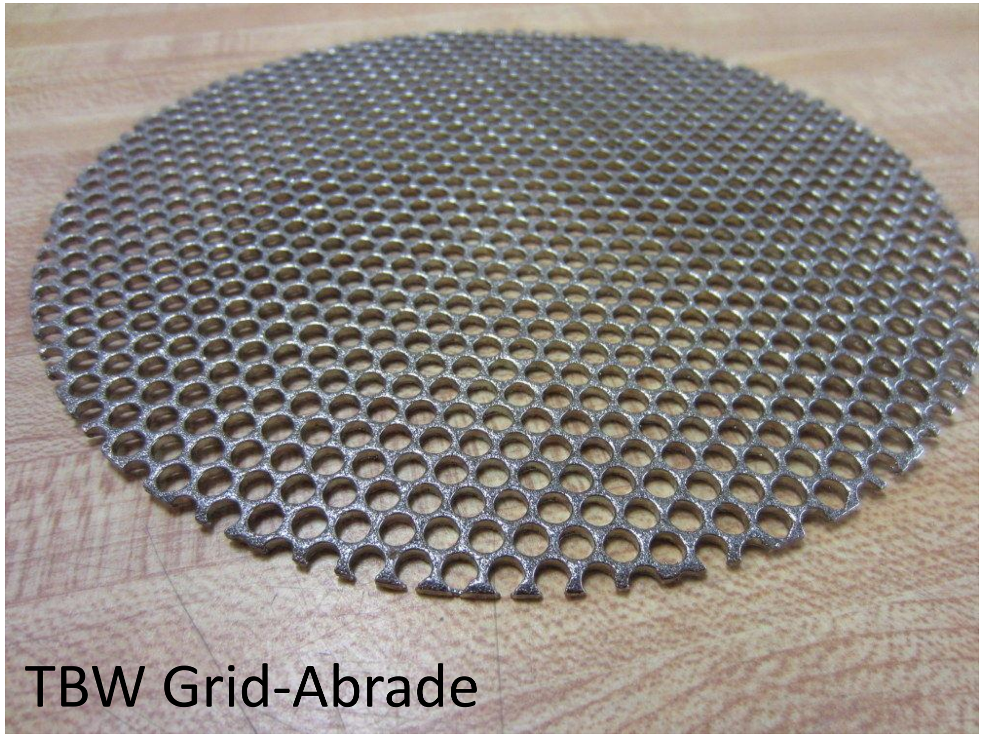


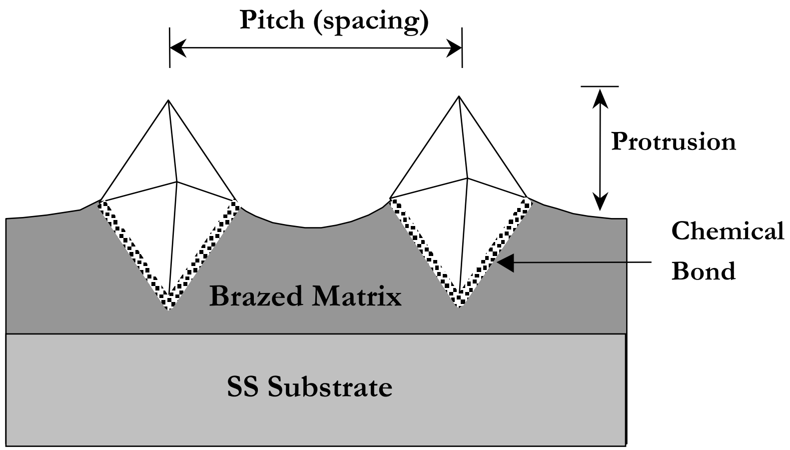
Photo courtesy of Mara Industrial Supply

- Early conditioner designs adapted existing grinding and polishing implement technology for CMP
- Pioneering companies such as ATI developed more advanced platforms, often at the urging of end users who were driving the technology

10. S. Qamar NCCAVS CMPUG, June 2005.
    Available online at: http://www.avsusergroups.org/cmpug_pdfs/CMPUG_2005_06_Ati.pdf

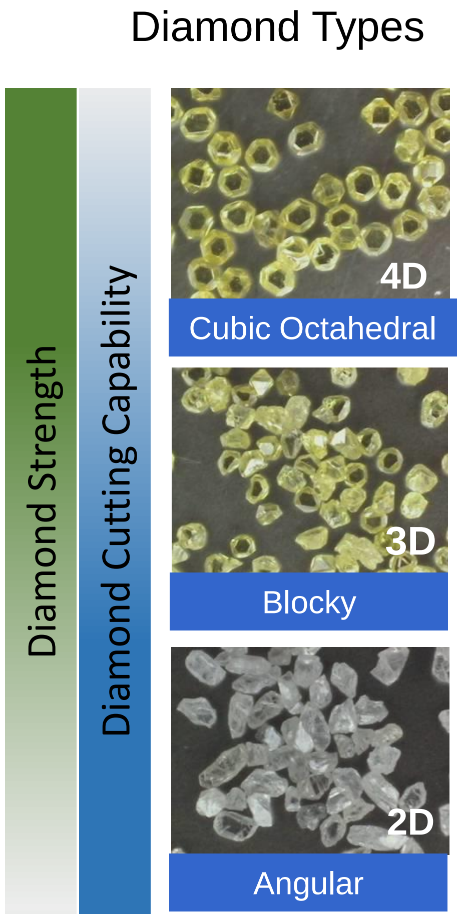
Pad Conditioner Architecture

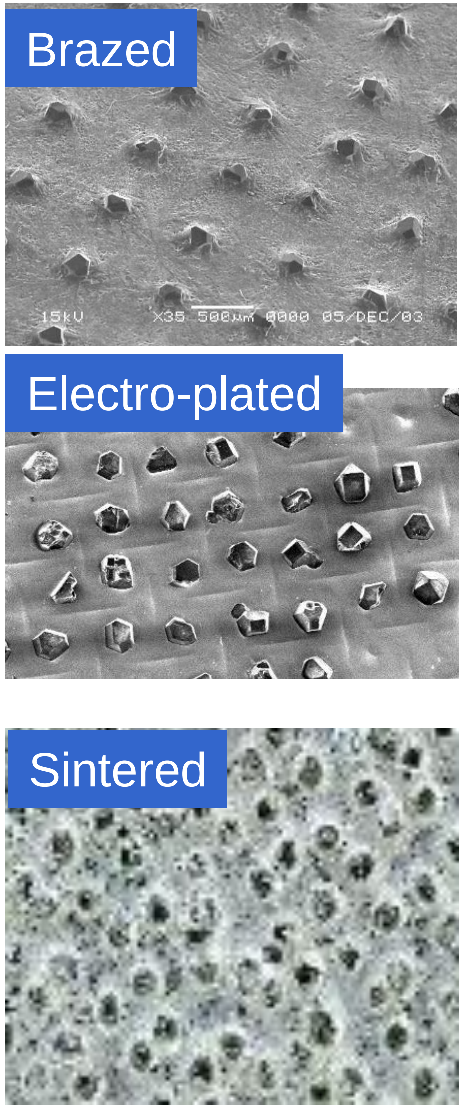
Disk Architecture



Features of advanced pad conditioner designs:

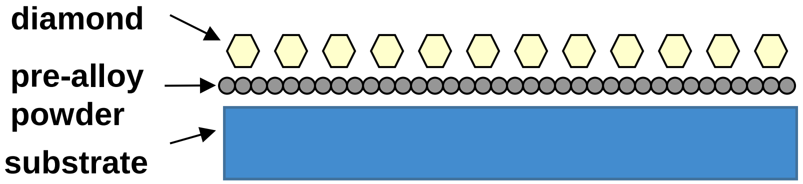
- Fixed diamond grid placement to optimize configurations for specific cut-rate/cut-roughness process requirements
- Tight uniformity of diamond height (levelling) and protrusion
- Advanced QC, including incoming magnetic sorting, size sorting and shape sorting and strength testing
- Factory pre-conditioning break-in and cut-rate testing



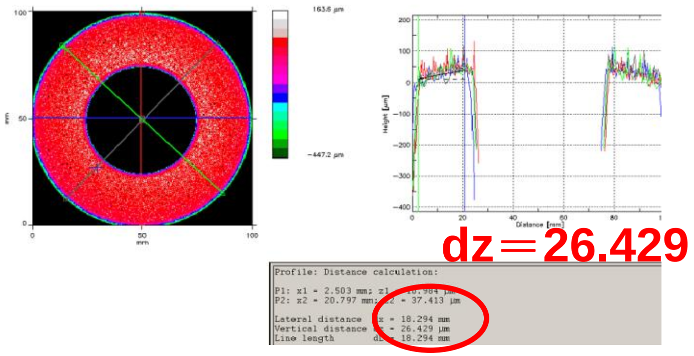


Kinik Flatness Evolution

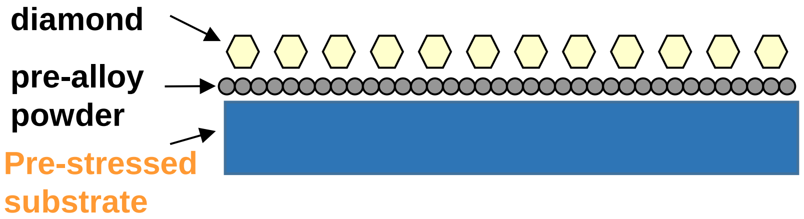
DiaGrid



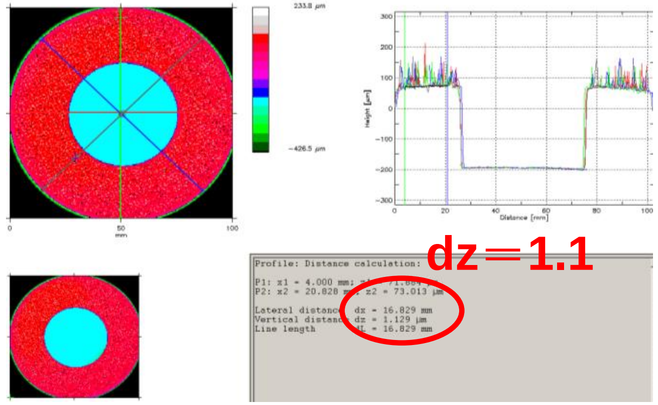
Vacuum braze



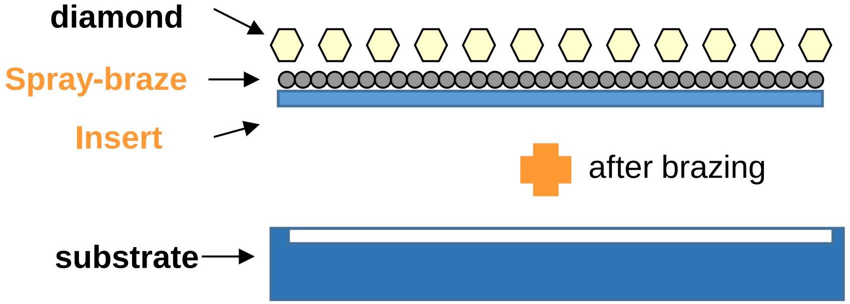
I-DiaGrid



Vacuum braze

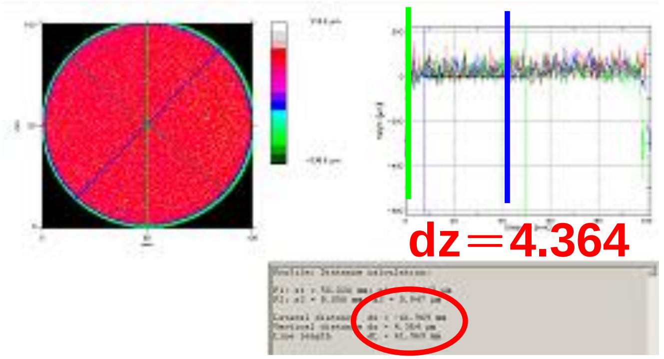


S-DiaGrid

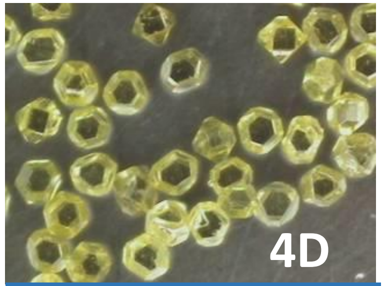


(allows magnetic Mount)

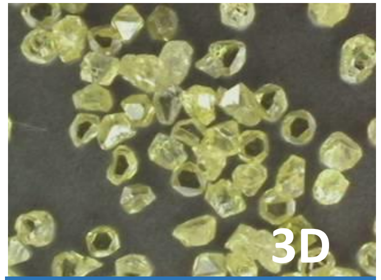
Vacuum braze



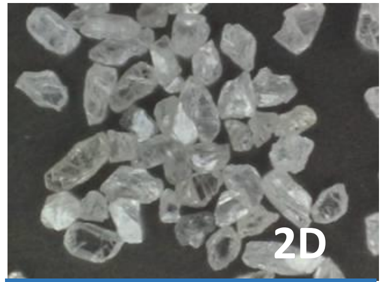
Kinik Diamond IQC and Sorting



Cubic Octahedral



Blocky



Angular

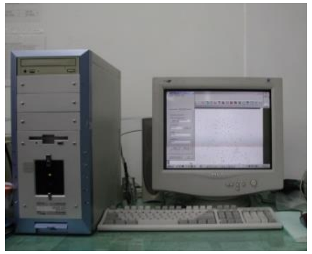
KINIK Diamond IQC Steps

Size Sorting Tool

Magnetic Sorting Tool

Shape Table

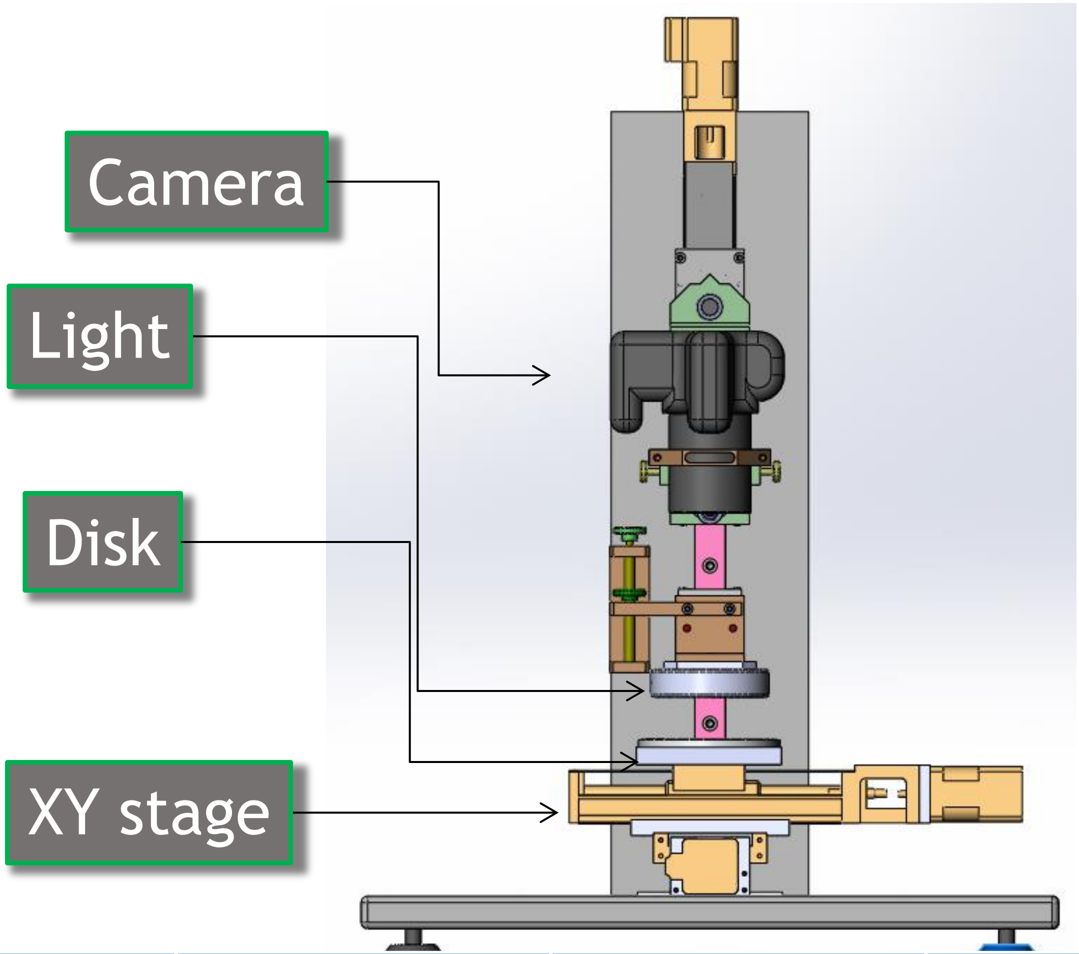
Strength Tester



Grain Size and Shape Analysis Tool

Incoming QC → Diamond Setting → Vacuum Brazing → Mid-Inspection → Pre-Conditioning → Final OQC

Kinik Final Inspection- Disk Imaging



- Disk image capture unit currently utilizes 16 million pixels
- The disk image system is automatically linked to a proprietary feature analysis software
- Taiwan patent has been granted for this technology

- Patented imaging system captures entire disc surface for comparison before and after polishing

Incoming QC → Diamond Setting → Vacuum Brazing → Mid-Inspection → Pre-Conditioning → Final OQC

Consequences of "Statistical Control" of Diamond Contact

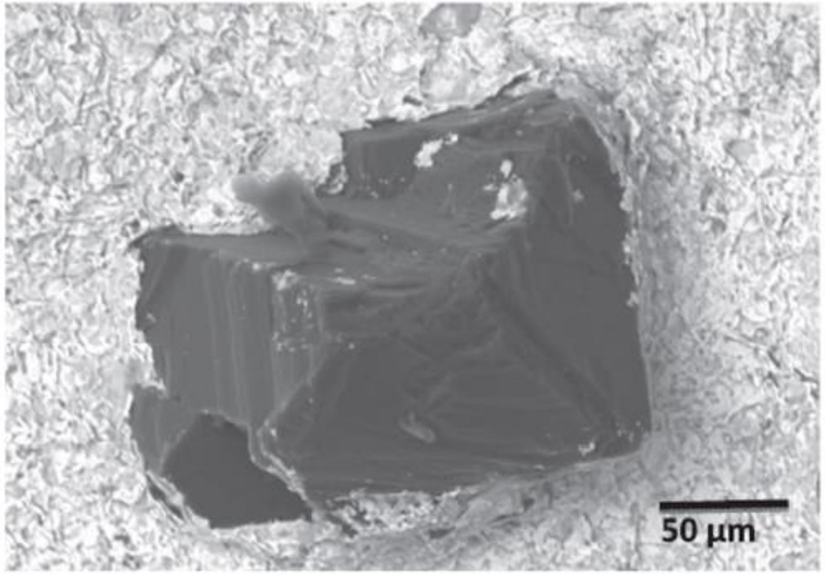


Figure 9. SEM image of a new "born" aggressive diamond.

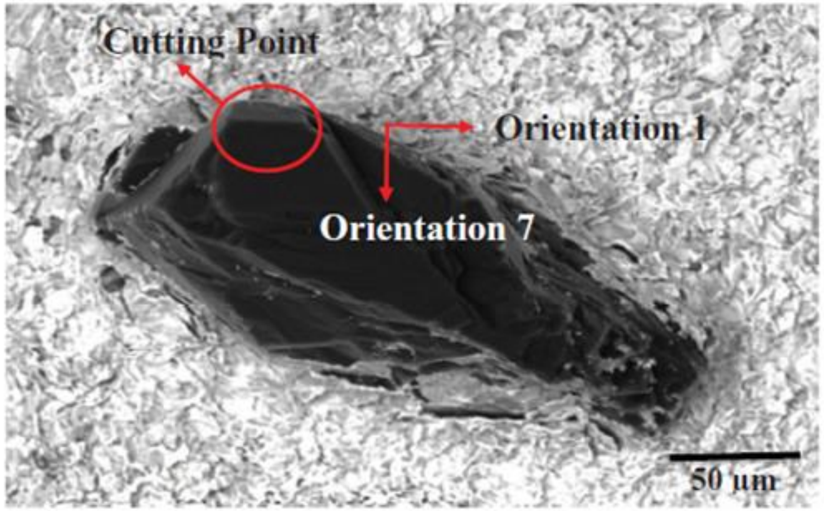
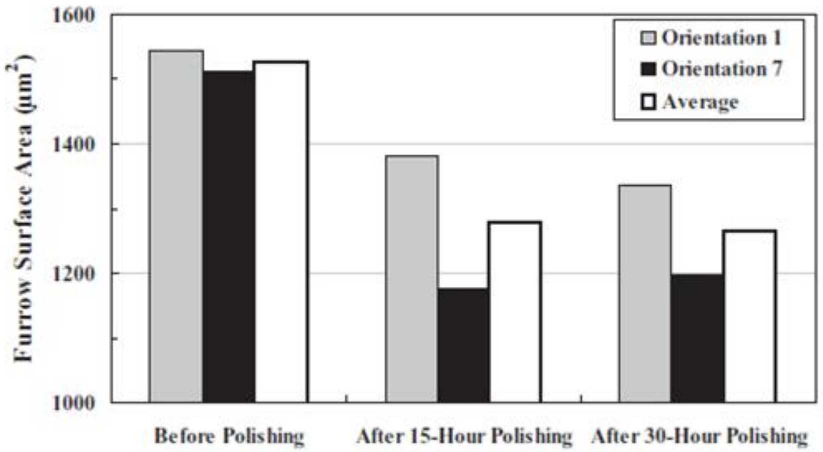


Figure 11. SEM image of a typical aggressive diamond.



- A handful of aggressive diamonds dominate the behavior
- A relatively wide height distribution results in initial cutting points wearing quickly and additional points coming in contact as disc wears
  - Cut rate drift/degradation
- Diamond orientation is extremely difficult (random)

11. Wu, et al., ECS Journal of Solid State Science and Technology, 2 (1) P36-P41 (2013)

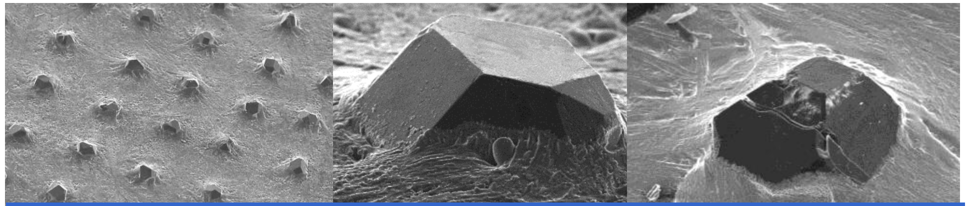
Traditional Design Issues

Low scratch defects require **STRONGER DIAMONDS** that will not fracture as well as robust fixing technology that will hold diamonds and not represent an additional contribution to defectivity

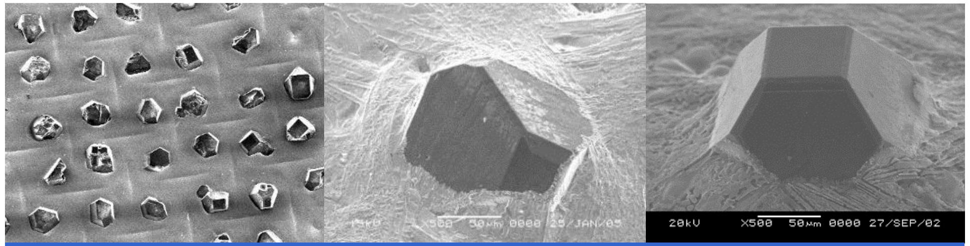
HEIGHT CONTROL New disks designs require fixed and control diamond protrusion. Standard disks have >20,000 diamonds to ensure consistent pad contact (consistency through averaging). Only a small fraction of true working diamonds

Diamonds can rotate and change orientation during manufacturing impacting levelling. New disk designs require controlled **DIAMOND ORIENTATION** (point, flat or line side-up diamond placement control)

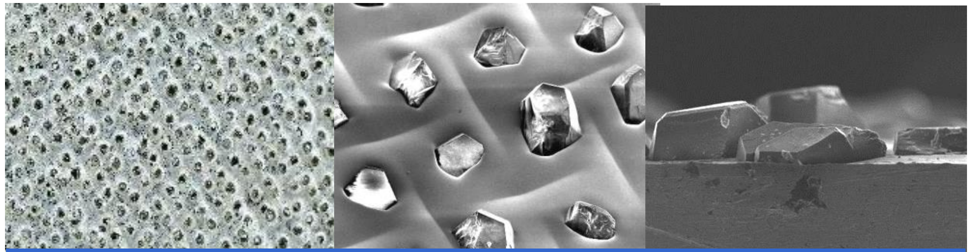
DIAMOND SHAPE controls pad cutting, surface asperity development and pad/disk interface interaction. Critical to design and control shape



Diamond Strength

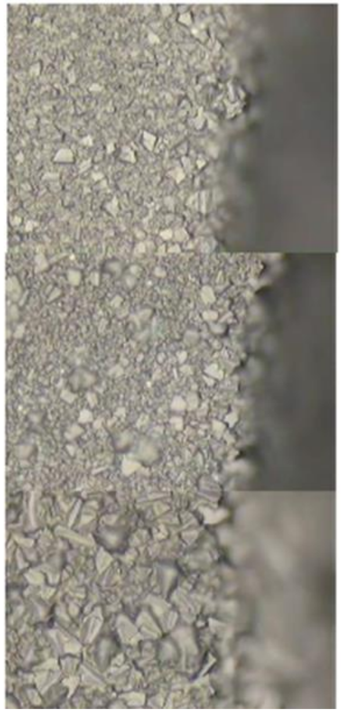


Diamond Orientation/Shape



Diamond Levelling

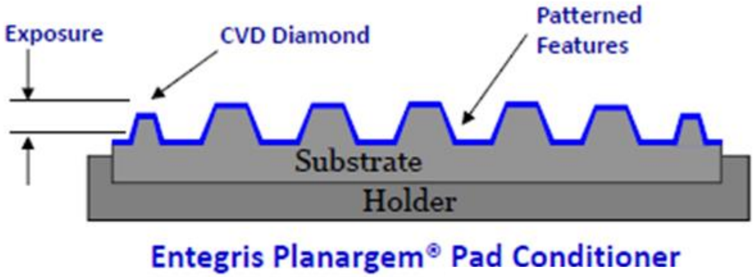
CVD Diamond/Fine Diamond Conditioners

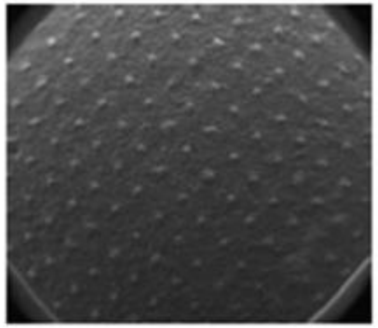


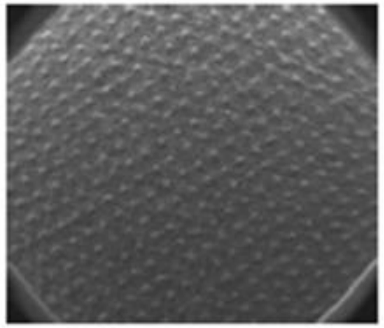
Design A

Design B

Design C







Morgan Advanced Materials

Entegris creating a material advantage

12. D. Slutz NCCAVS CMPUG, July 2008.
Available online at: http://www.avsusergroups.org/cmpug_pdfs/CMP2008_7_Slutz.pdf

13. R.K. Singh et al. NCCAVS CMPUG, May 2013.
Available online at:
http://www.avsusergroups.org/cmpug_pdfs/CMP2013_5RSingh-Entegris.pdf

Micro-Replicated Conditioners

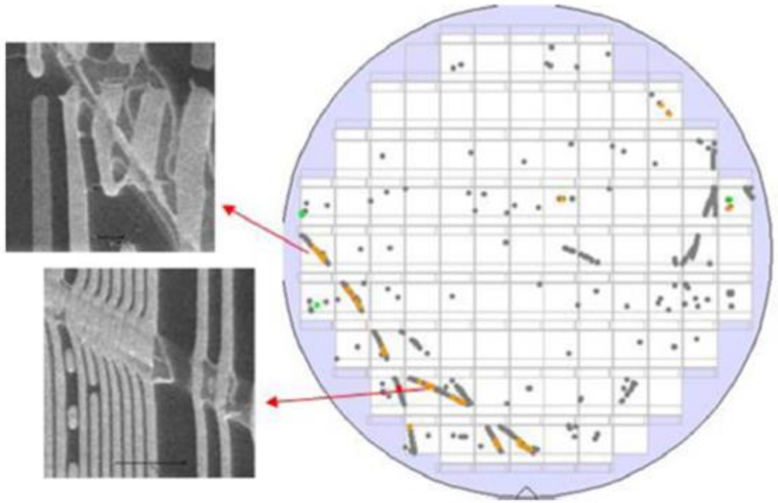


Figure 10. Type III scratches: deep and severe scratches with arc spatial signature as observed with type A conditioner.

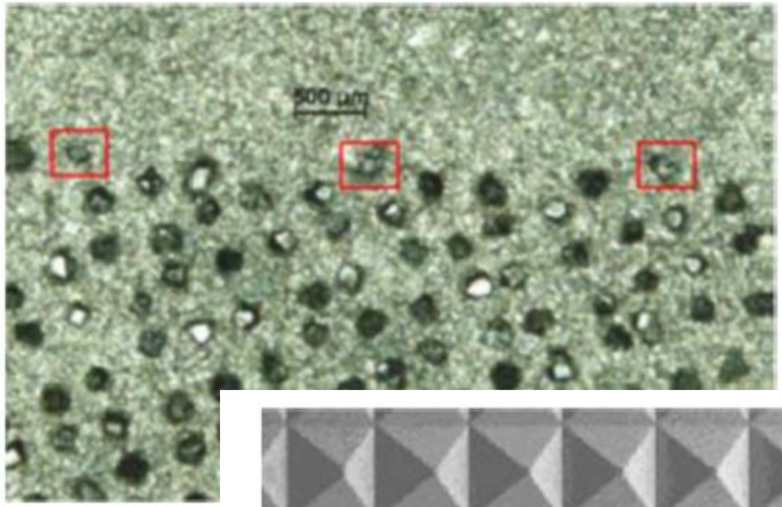


Figure 11. SEM insp
grits after 1000 wafer
in Type III scratches a

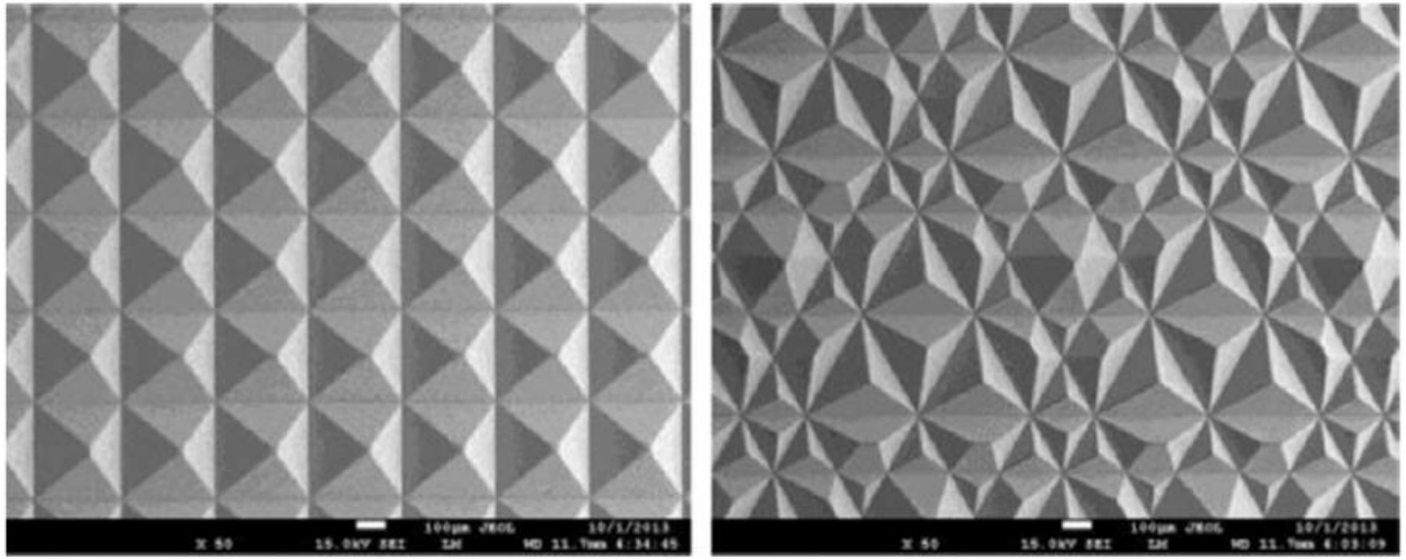


Figure 5. SEM top-down images showing the surface patterns of the two microreplicated pad conditioners evaluated in this work. Type M1 (*left*) and type M2 (*right*).

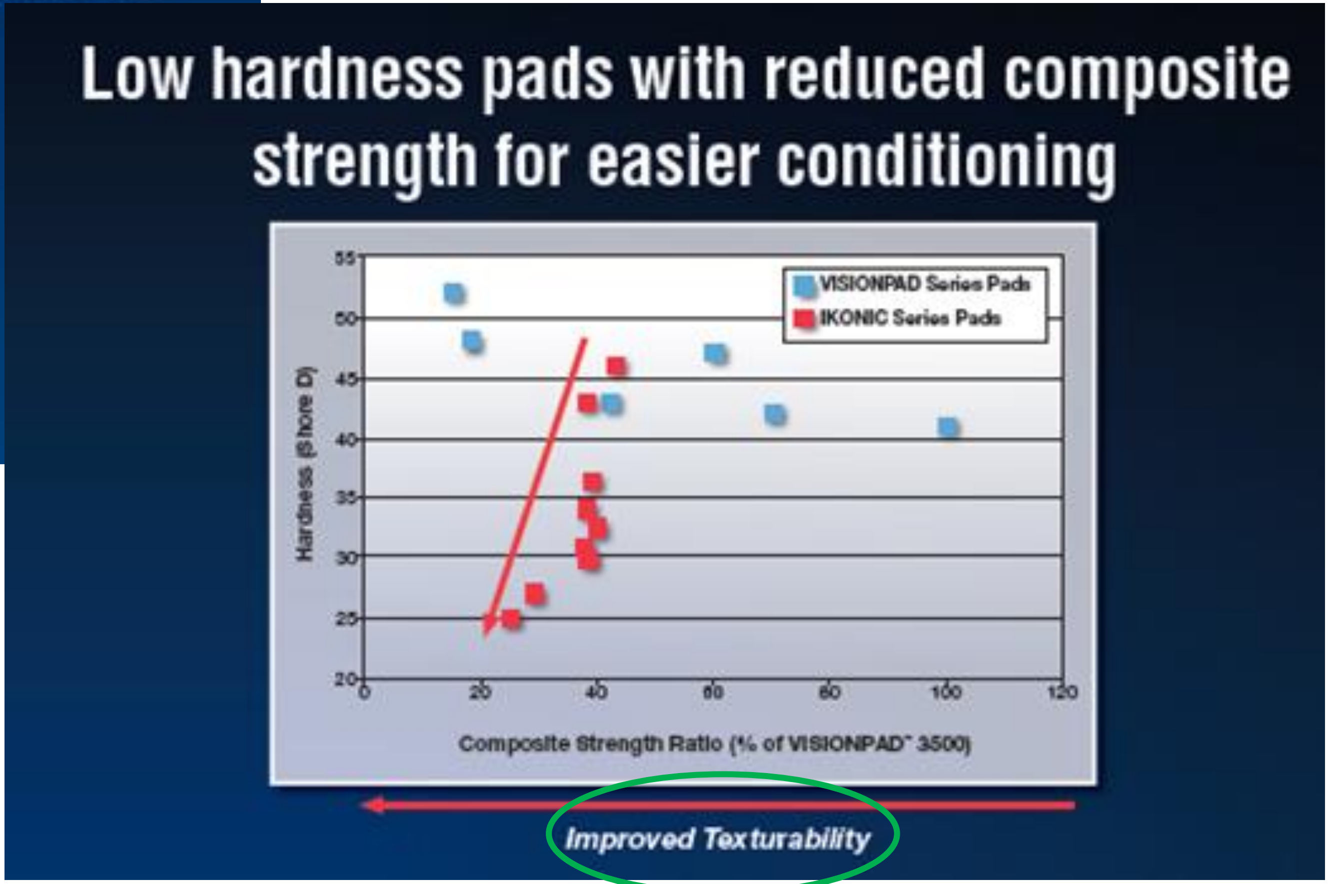
- Discrete control over cutting behavior
- Potential defectivity improvements
- Relatively low cut rates
- Low surface roughness

14. Tseng, et al., ECS Journal of Solid State Science and Technology, 4 (11) P5001-P5007 (2015)

Pads Designed for Their Conditionability

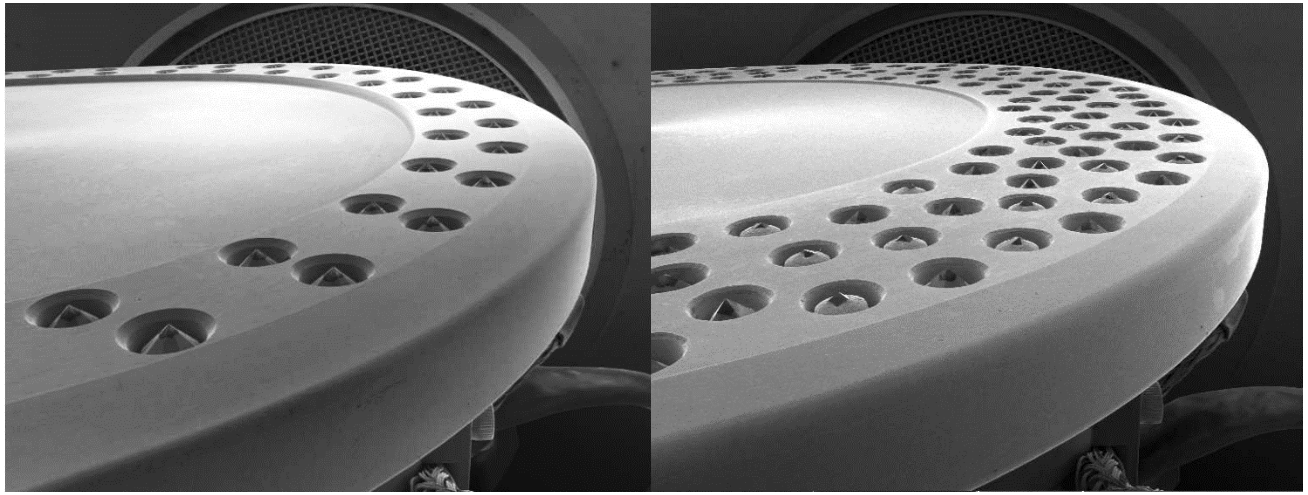
Benefits:

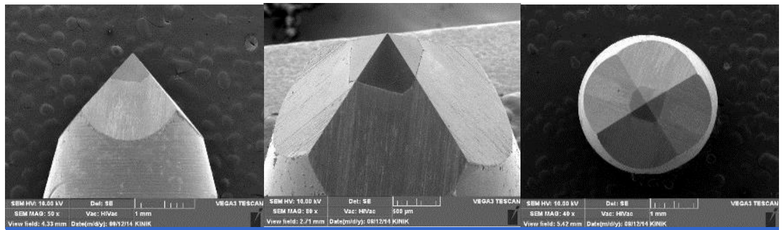
- Step-out defectivity performance
- Multiple offerings to meet a range of removal rate and selectivity requirements
- Extended pad lifetime
- Easily conditioned pad surface



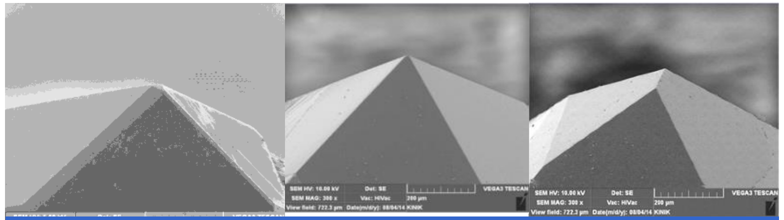
15. Poster associated with press release: “Dow Unveils First CMP Polishing Pads from its New IKONIC™ Pad Platform”
Available online at: http://www.dowelectronicmaterials.com/pdfs/ikonic-info-1.pdf

Pyradia™ Diamond Technology

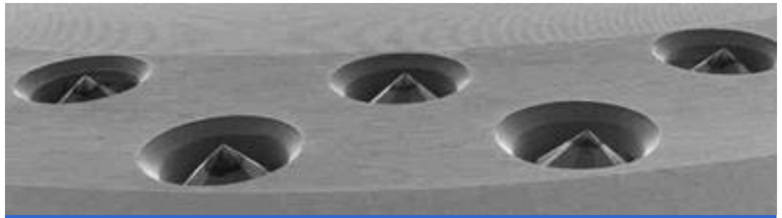




High Strength Diamonds



Ultra Precision Diamond Shaping Technology (UPDST)

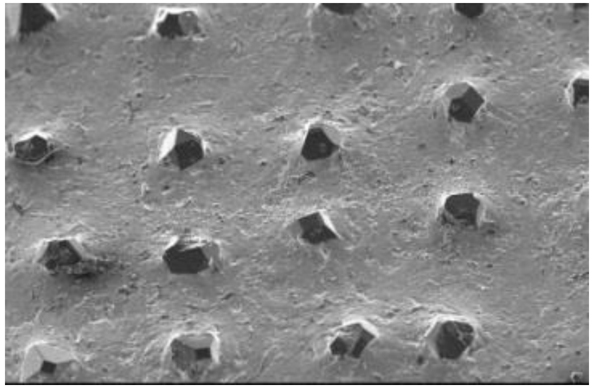
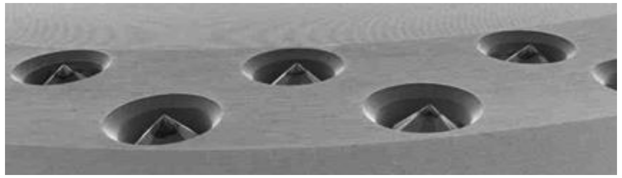


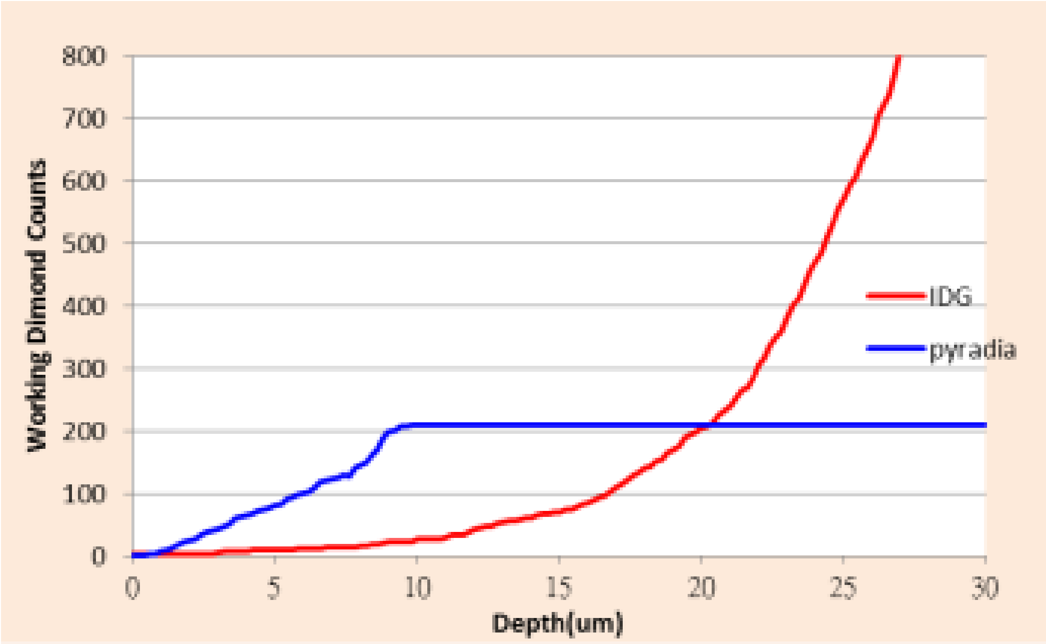
Fixed Diamond Placement

Pyradia™ disks utilize a combination of high diamond strength, diamond shape technology and individually oriented and fixed diamond placements to provide step-out performance, consistency and COO:

- Fixed diamond protrusion/levelling and designed shaped diamonds for specific pad contact for cut-rate, roughness and pad texture stability
- High diamond strength for low defectivity
- HVM product-product consistency for process stability
- Wide configuration flexibility and enabling for CMP process optimization

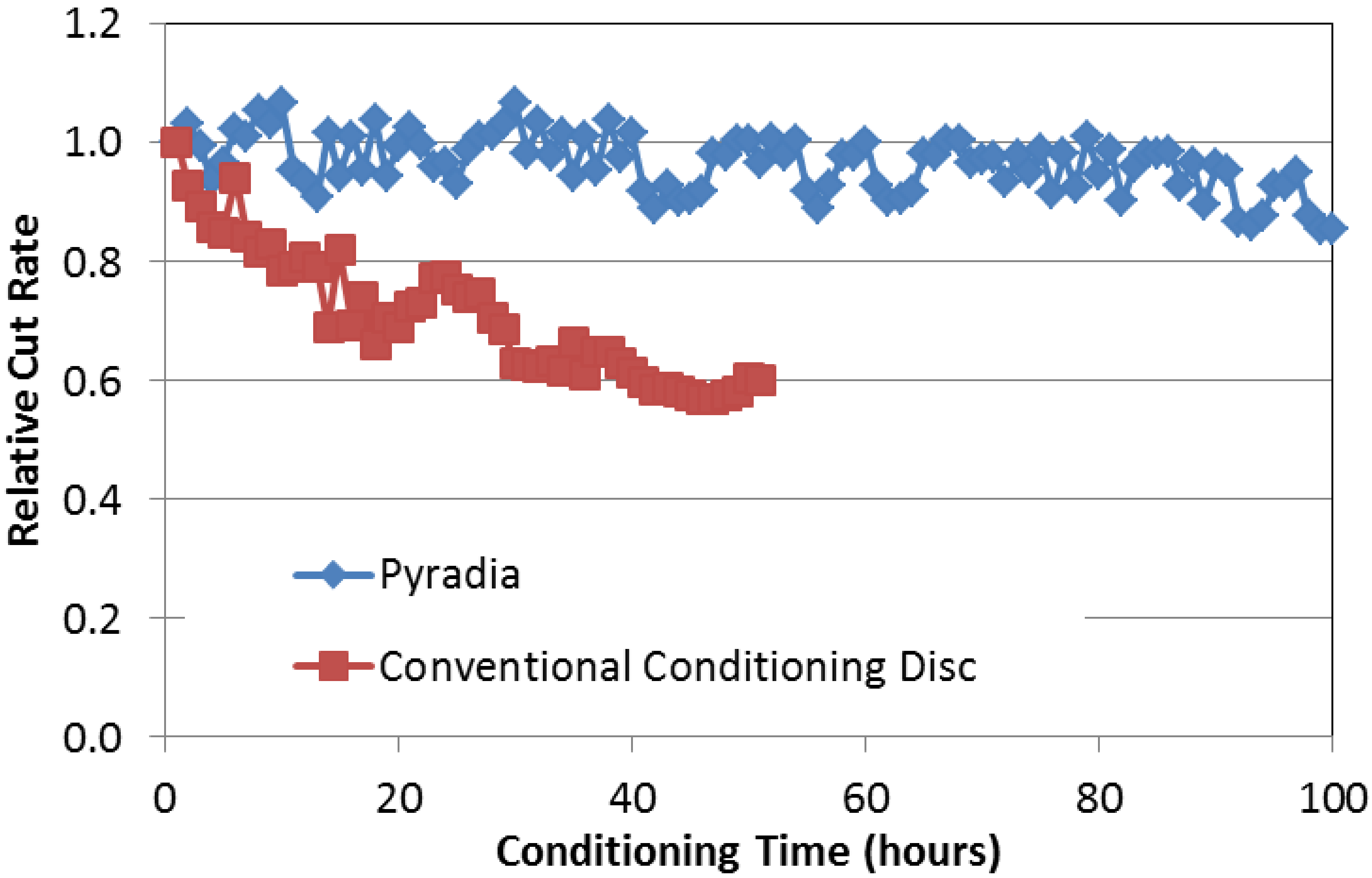
Diamond Height Control

Conventional	pyr∆dia®
	
	



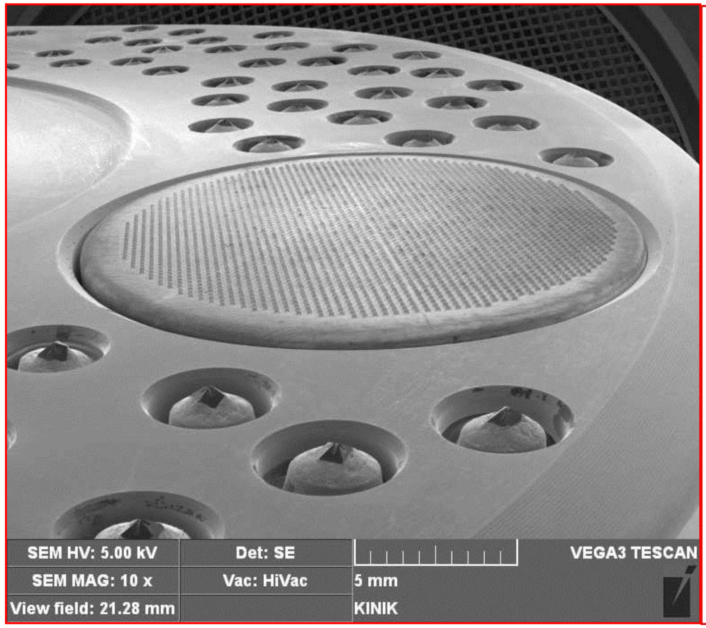
- **<u>All</u>** (~200) of the working diamonds on the Pyradia disc exhibit a protrusion height range of **<u>less than 10 µm</u>**
- The tallest 200 diamonds on the conventional disc exhibit a protrusion height range of 20 µm, and the full protrusion height range of the working diamonds is likely much higher than that

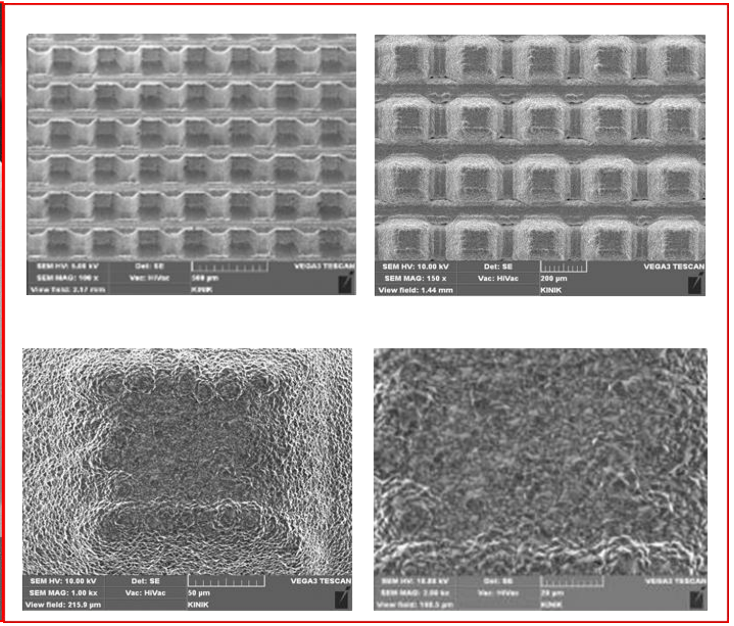
Cut Rate Stability

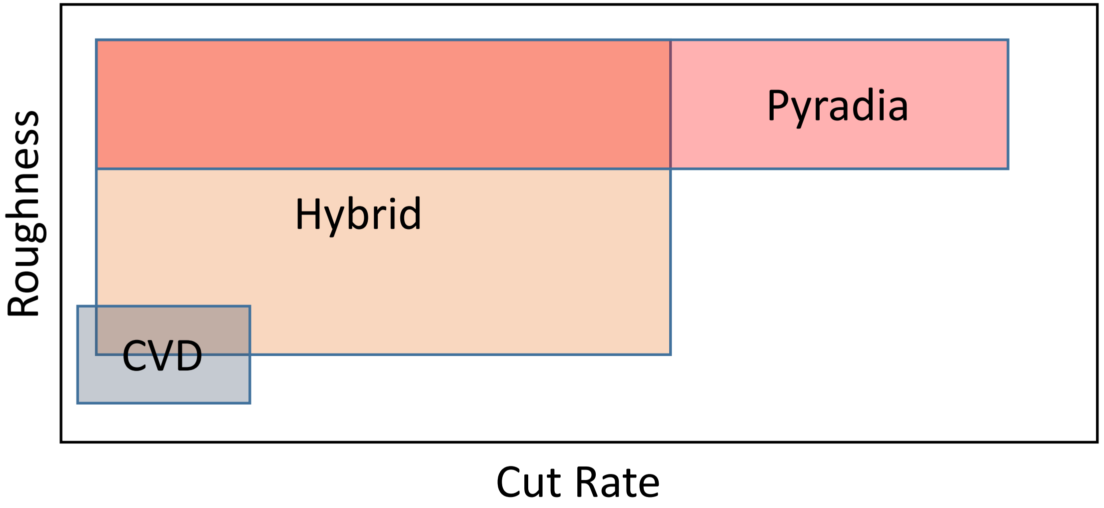


- The Pyradia disc exhibits superior cut rate stability due to the much improved cutting tip height control compared to the conventional disc
- Therefore, the asperity wear-cut rate balance is maintained for longer times
- So, conditioner designs with lower cut rate can be utilized because you don't have to "cheat" the process margin as much at beginning of life
- Or, disc life can be increased significantly

Hybrid CVD/Pyradia







- The Pyradia platform can incorporate CVD pads
- These precisely shape and protrusion controlled CVD pads modulate the cutting behavior, enabling the achievement of lower cut rates and smoother pad surfaces

Summary

- Pad conditioning is critical to CMP performance both in terms of absolute metrics (polish rate, planarization, defectivity) and the stability of those metrics over time
  - The surface texture of the pad can be analyzed, quantified, decoupled and tied to polish performance
  - Pad conditioner cutting behavior drives the pad near surface
  - Pad properties and conditioner design combine and interact to determine the overall structure of the pad surface
  - These factors can be taken into account to drive and support next generation conditioner and process design
- As the process understanding of conditioning has evolved, so has the sophistication of conditioner hardware
  - From the initial adoption of available technologies, to the development of specialized platforms and advanced statistical control
- State of the Art and Next Generation conditioning platforms aim to improve discrete control of cutting behavior
- Future advances will improve the synergy between pad, conditioner and process design