CMP Pad Conditioning and Applications to Soft Pads

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Introduction

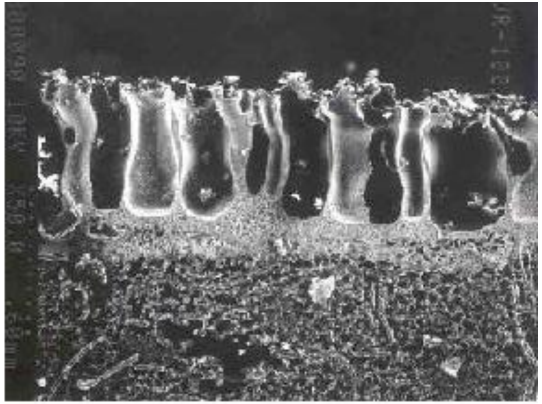
- "Soft Pad" conditioning has become more critical
  - Conditioning of poromeric pads has become more important
    - Poromeric materials (Fujibo H800, DuPont OVP9500) have a vertically oriented pore structure and performance is tied to pad thickness
- Conditioning of impregnated felt (Type 1 or "Suba-like") pads is becoming important in emerging substrate applications
- The modeling and analysis tools developed for Type 3 and 4 pads can be readily applied to Type 1 pads
- The core roughness of Type 1 pads can be driven across a wide range with pad conditioning
- Pad analysis reveals changes in the pad surface structure associated with polishing indicating that more robust conditioning protocols could improve performance in Type 1 pad applications

CMP Pad Types

Type I

- Polymer impregnated felt
- Examples: Suba IV, 400, 800
- Not typically used in CMP, except as a subpad
- Stock polishing, SiC polishing
- “Soft”

Type II

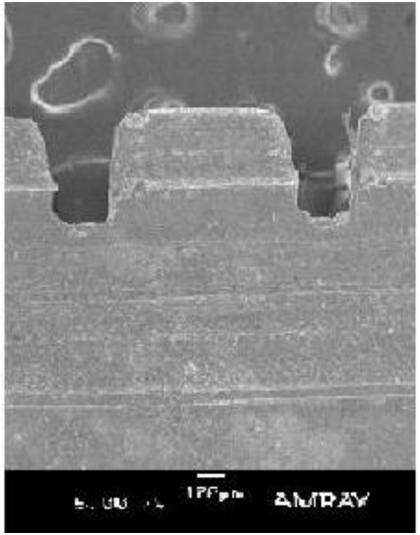


- Poromeric
- Examples: Politex, Fujibo H800, DPM/SPM 3100, OVP9500
- Vertical pore structure
- Also used as a subpad
- “Soft”

Type III

- Filled polymer sheets
- Examples: IC1000, D100, VP5000, IK4250, etc.
- “Uniform” pore structure in all directions
- “Hard”

Type IV

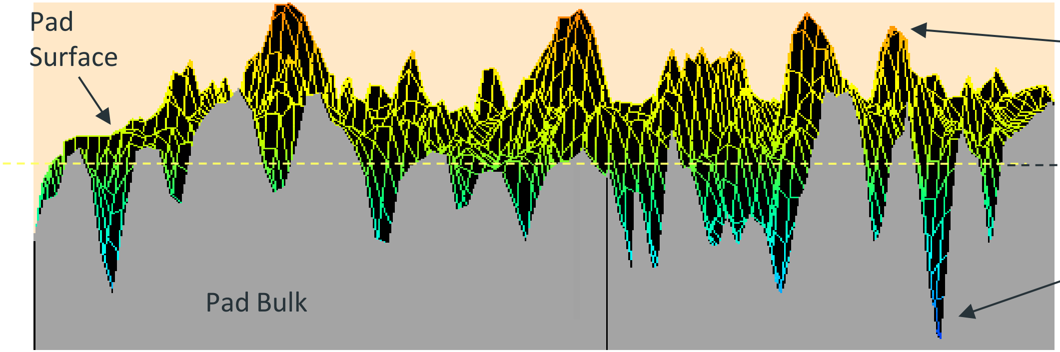


- Unfilled polymer sheets
- Examples: OXP3000/4000, TWI
- Solid, no intrinsic porosity
- “Hard”

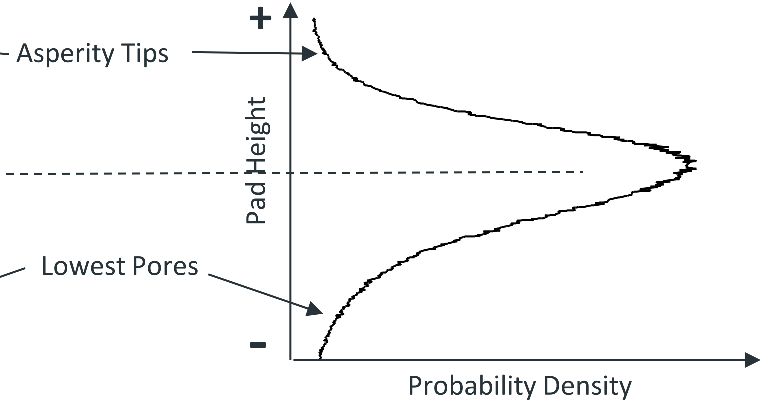
After D.B. James in, Chemical-Mechanical Planarization of Semiconductor Materials, M. R. Oliver (ed.) 2004

Pad Surface Statistics

Pad Surface 3-Dimensional Data



Pad Surface Height Distribution

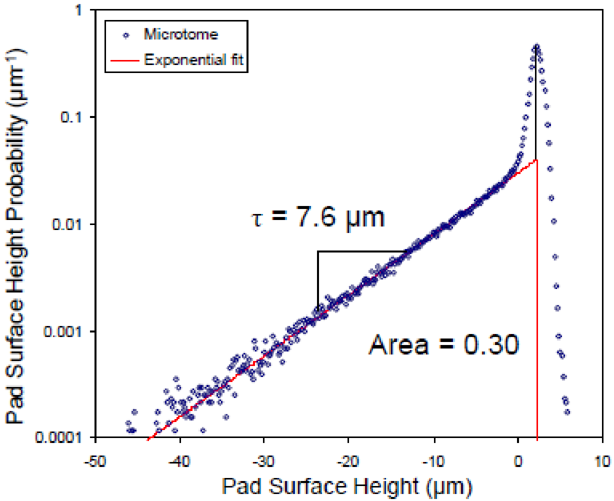


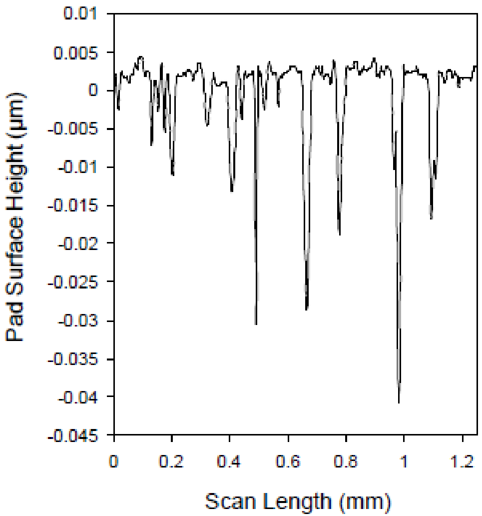
- **Pad texture is typically measured via Laser Confocal Microscopy or Vertical Scanning Interferometry**
- **The pad surface height probability distribution function (pdf) describes how the pad surface is distributed in vertical space**
- **The most positive side is in contact with the pad, the most negative side represents the lowest visible pores**

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

Pad Intrinsic Porosity

IC Porosity Distribution from Microtomed Sample





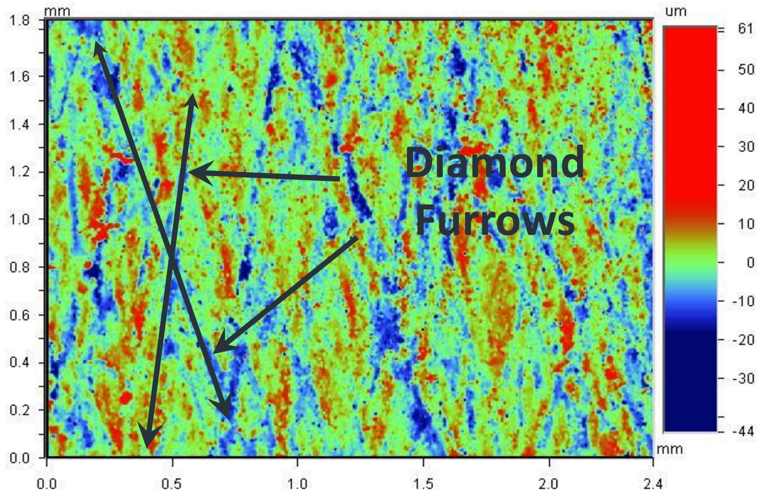
- The microtome yields a surface with a very low imposed roughness and enables a more direct measurement of the porosity distribution

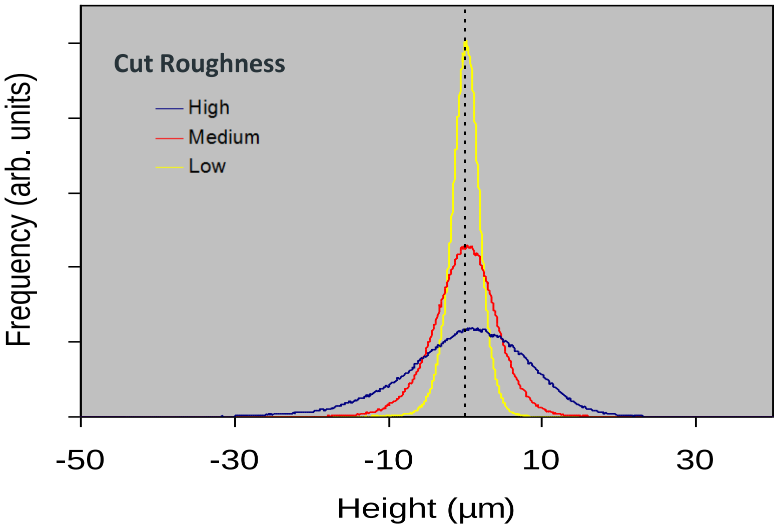
- **Accurate determination of the porosity distribution can provide the basis for specification of "compatible" conditioning protocols**
- **The characteristic decay length of the exponential (τ) can be compared to the half height half width of the Gaussian mode**
  - **If the Gaussian mode (i.e. the characteristic depth of the conditioner cut) is too wide it will effectively "swamp out" the intrinsic porosity distribution of the pad**

Slide courtesy of Dow (now DuPont Electronics and Imaging)

Conditioning Induced Roughness

Conditioned Solid Pad Surface

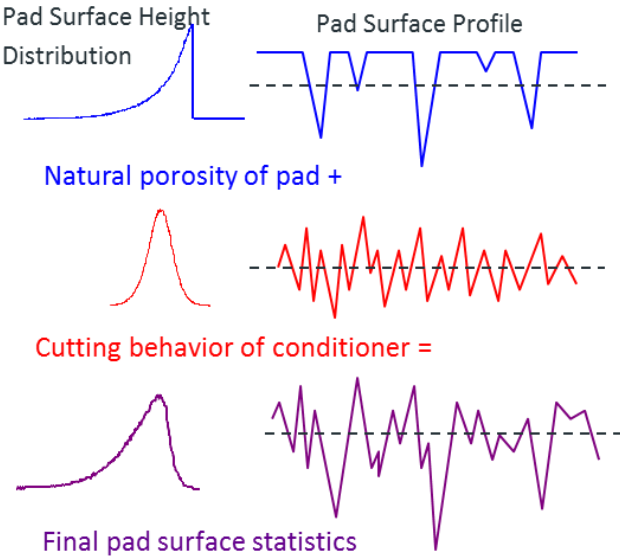


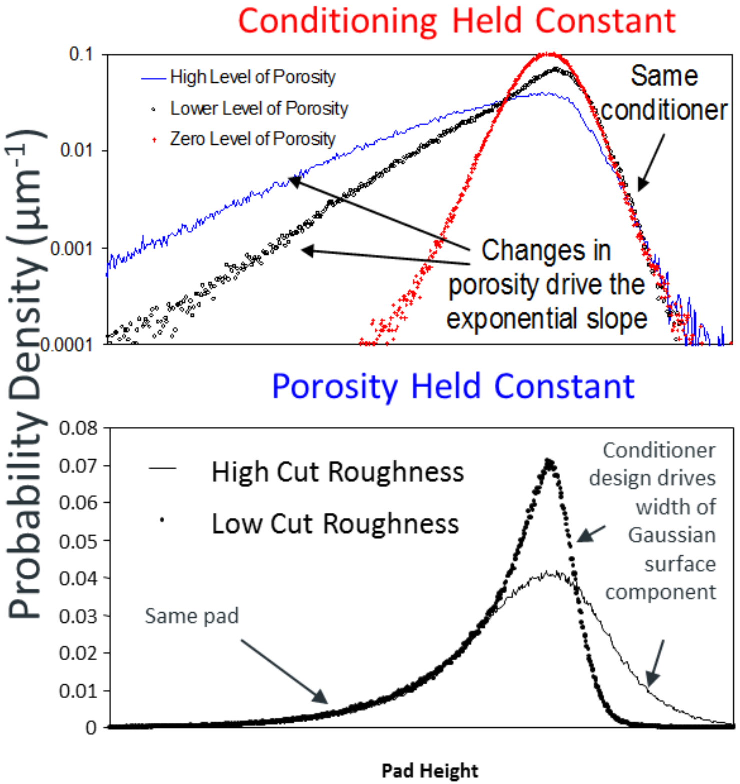


- In the absence of "built in" porosity, the conditioner alone determines pad surface texture
- Conditioner design variables determine the nature of the individual furrows which build up to form the pad texture
- This example shows three different conditioner designs which impart a dramatically different surface roughness to a solid pad
- A Gaussian distribution is typically an excellent model for the conditioning imposed roughness

Adapted from A.S. Lawing NCCAVS CMPUG, May 2004.
Available online at: https://nccavs-usergroups.avs.org

Pad Surface Texture



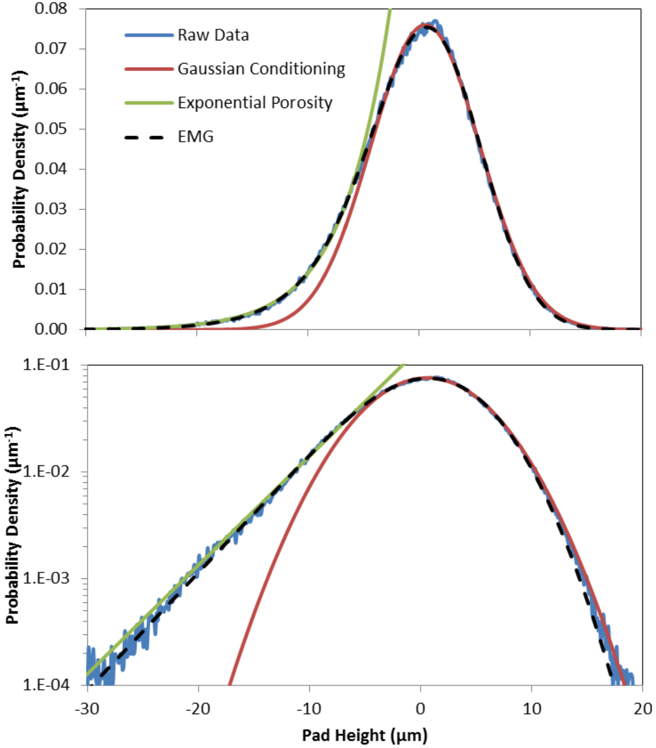


Topics in Plasma Science and Thin Film Applications III -in Honor of Herbert H. Sawin : AS Lawing Nov 2008

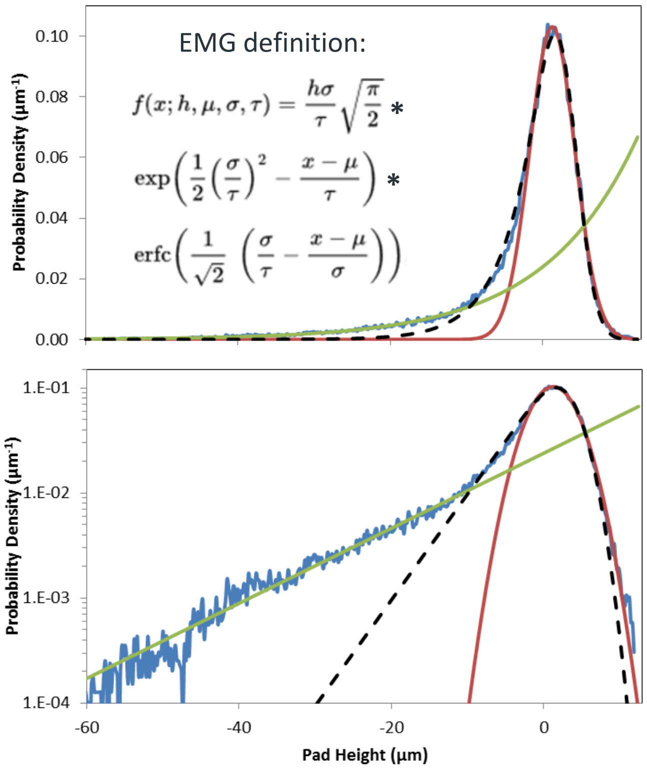
- Final pad surface is the product of the inherent pad texture **(porosity)** and the conditioner cutting characteristic **(near surface roughness)**
- Each pad-conditioner combination will have a **unique (intrinsic) surface structure**
- Cut rate, cutting characteristics and the resulting near surface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

Modeling Pad Height Distributions

Good EMG Fit

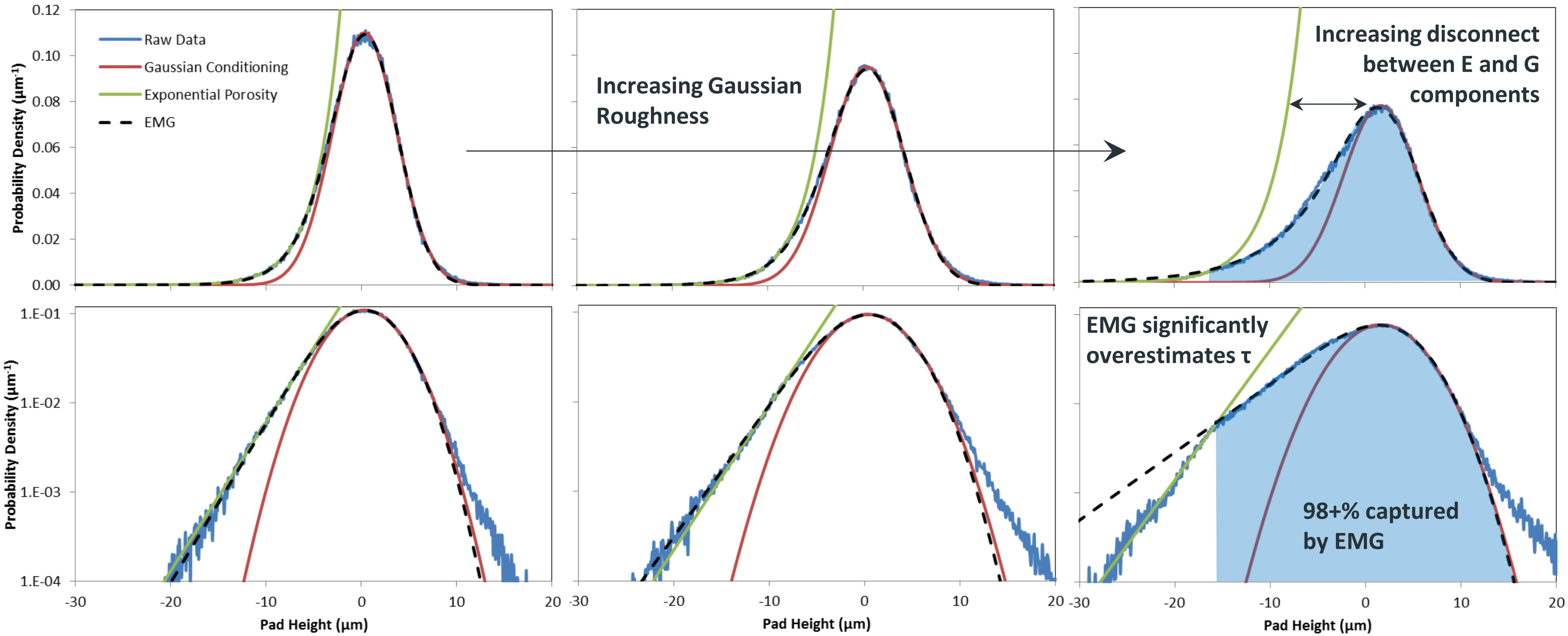


Poor EMG Fit



- **Exponentially Modified Gaussian**
  - **The EMG is a mathematical convolution of an exponential with a Gaussian – basically a Gaussian "front" with an exponential "tail"**
  - **The exponential parameter of the EMG is equivalent to an independently derived exponential slope**
  - **The EMG Gaussian parameter is not exactly equal to the σ of an independent Gaussian except at very low values of τ**
  - **EMG was developed for chromatography but provides an excellent description in cases where there is a smooth transition between the E and G components**
- **De-coupled Exponential/Gaussian**
  - **The de-coupled model treats each component independently, providing greater flexibility**

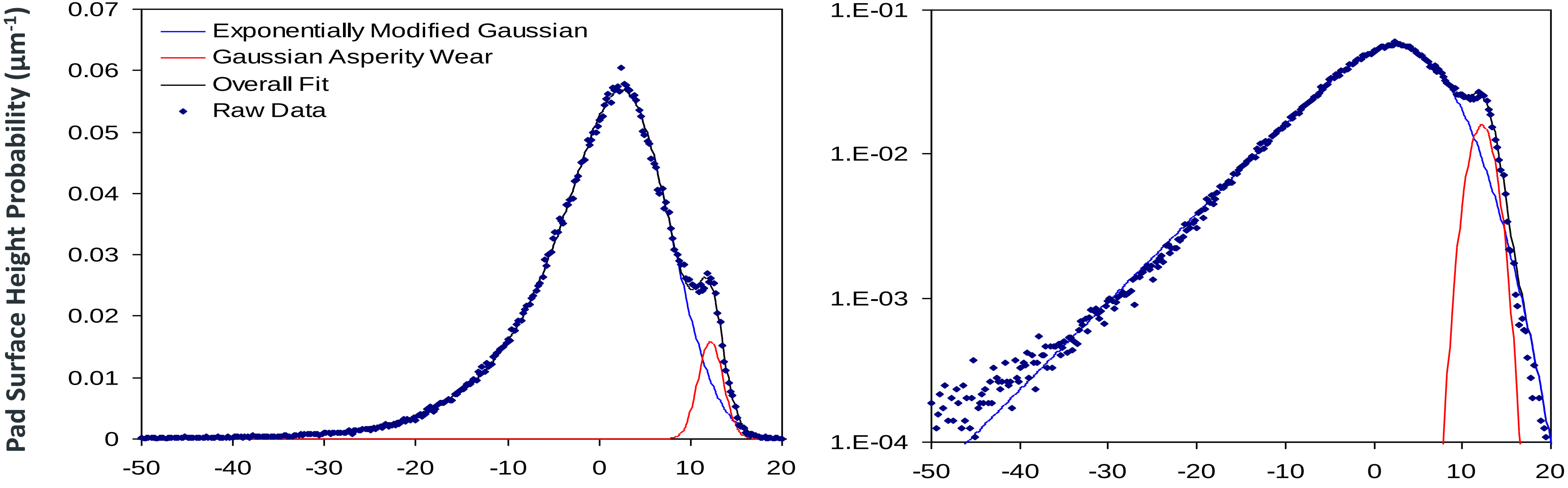
Modeling Pad Height Distributions



- In this example, both the EMG and the decoupled model provide apparently robust fits, but a detailed analysis reveals that the EMG model doesn't capture critical detail in the porosity signature

See also: Lawing, Pad and Conditioner Integration in CMP, ICPT 2019

Asperity Truncation (Glazing)



- **Pad surface asperities become truncated under polishing stress in the presence of aggressive slurry chemistry and abrasive particles**
- **On Type 3 and 4 pads, asperity truncation can be modeled as an additional Gaussian mode in the height distribution**
- **Changes in the pad surface lead to changes in pad wafer contact and changes in polish performance**
- **In addition to setting the asperity structure, a key role of pad conditioning is to maintain the structure through the removal of truncated material and re-establishment of the intrinsic texture**

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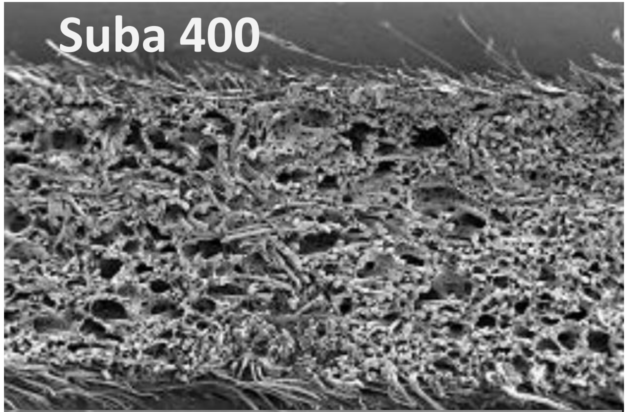
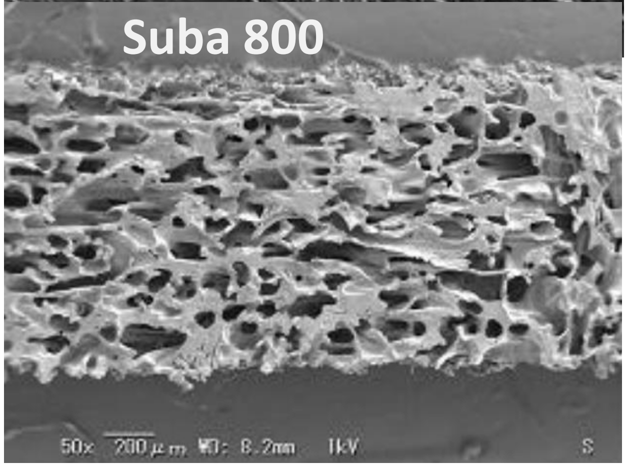
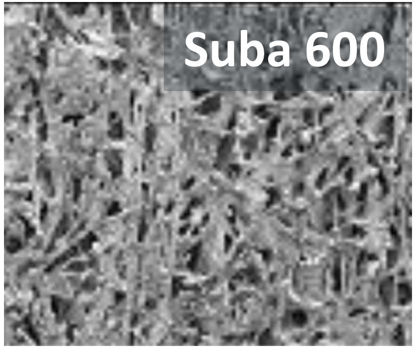
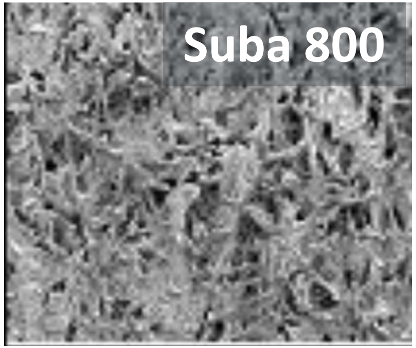
Type 1 ("Suba") Impregnated Felt Pads





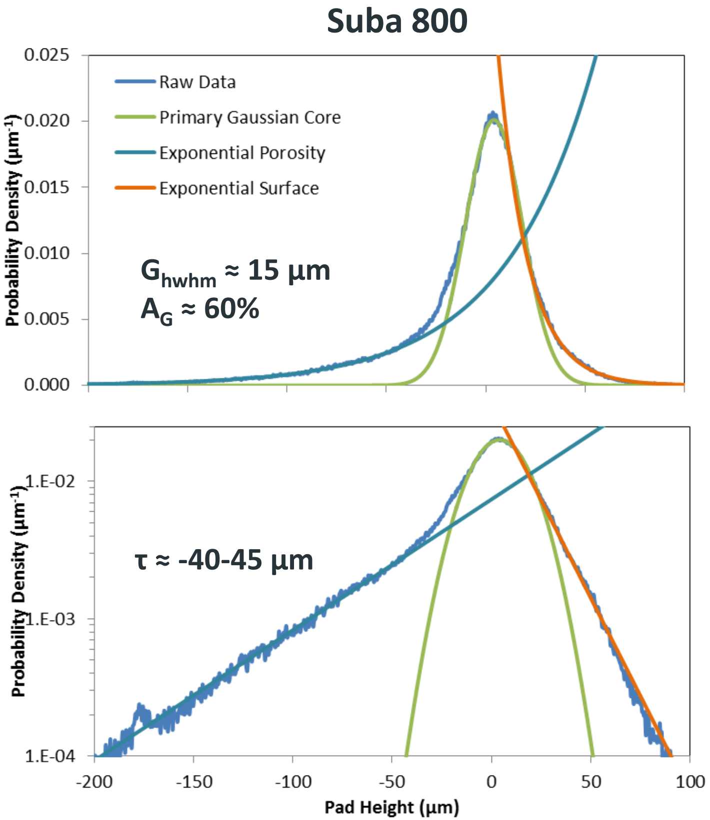




- Type 1 pads consist of non-woven (needled) polyester fibers impregnated with polyurethane
- Pad properties depend on fiber variables (type, thickness) and impregnation (type, number of impregnations)
- Type 1 pads are typically buffed to impose an initial texture

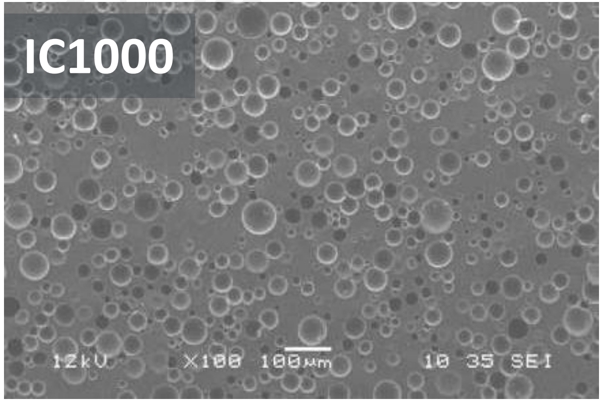
Images available online at:
http://www.anchor-t.co.jp/article/15065811.html
https://www.nittadupont.co.jp/en/wp-content/uploads/sites/3/2014/07/2a3ffc2acd25bf43ebdf222e317f64b11.pdf

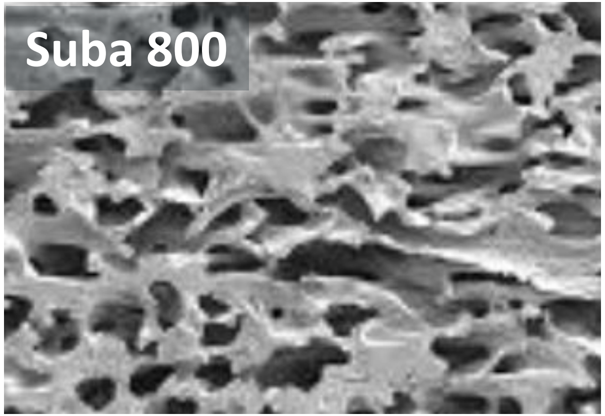
Model For Suba Type Pads



- The new pad surface exhibits a Gaussian core with an exponential describing both the porosity and the pad near surface
- The exponential porosity component is typically consistent within a given material type
- The Gaussian core is dependent on the pad surface treatment (buffing, conditioning) and the effects of the polishing process
  - The Gaussian Core accounts for the majority of the measured surface on a new Suba pad
  - We have measured the Gaussian core roughness for new Suba 800 from about 15 to 28 µm
- Measurements of Suba 400 reveal differences in both the native porosity and the buffing treatment between these materials

Length Scales Compared to Type 3 Pads





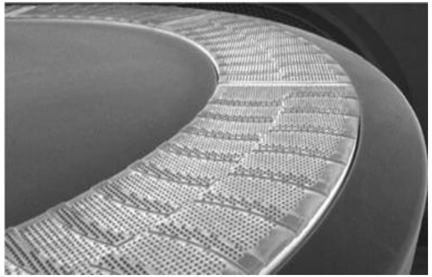
- Type 3 pads typically exhibit exponential decay constants in the range of 10 µm or less, and most typically between about 2.5 – 7 µm
- Type 1 pads exhibit exponential decay constants of 40 - 75 µm

- The same range of pad conditioner designs that develop Gaussian core roughness of 2 - 7 µm on a Type 3 pad will contribute to 10-30 µm core roughness on a Type 1 pad

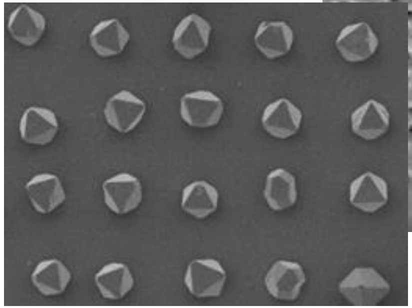
- The length scales of interest on a Type 1 pad are almost an order of magnitude larger compared to Type 3 pads

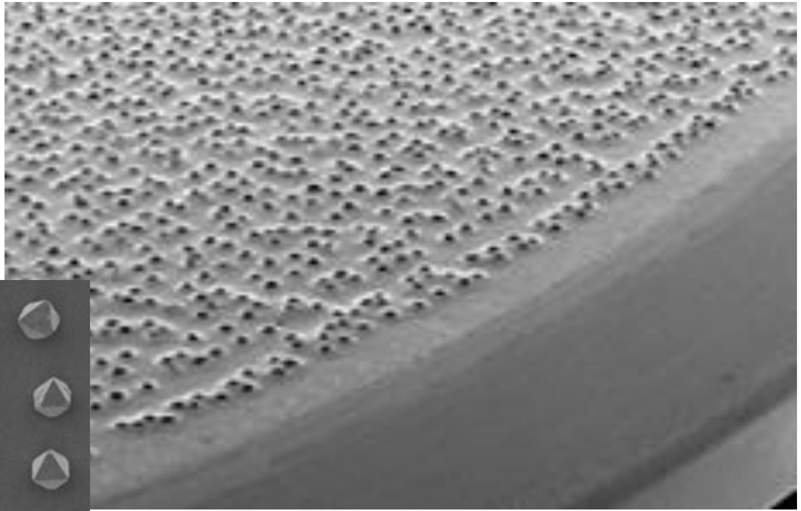
Images available online at:
http://www.anchor-t.co.jp/article/15065811.html
https://www.nittadupont.co.jp/en/wp-content/uploads/sites/3/2014/07/2a3ffc2acd25bf43ebdf222e317f64b11.pdf

Suba 800 Pad Conditioning Matrix



Brush



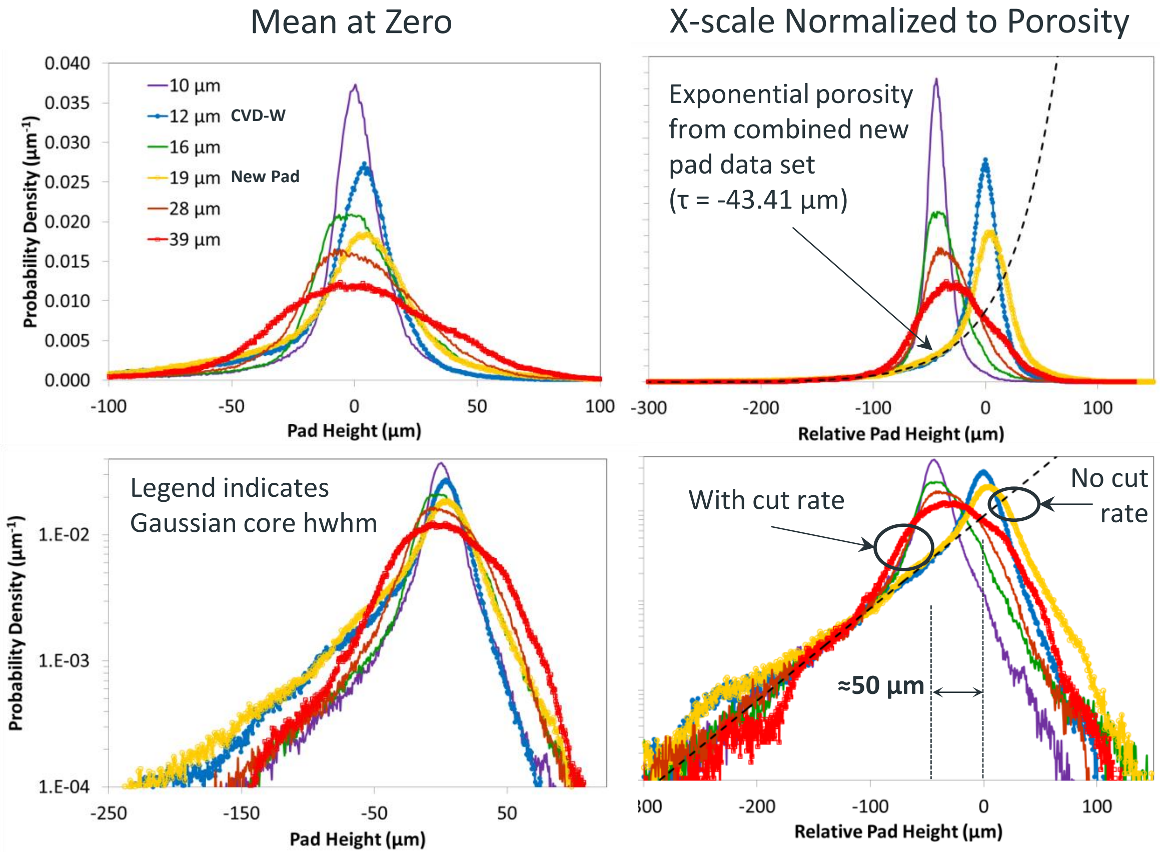


Conventional Diamonds

- A range of conditioner designs were selected to test in the HCR cut rate tester on Suba 800
  - Large, Medium and Fine diamond discs in the range of 50 ~ 350 µm
  - CVD-W
  - Bristle Brush

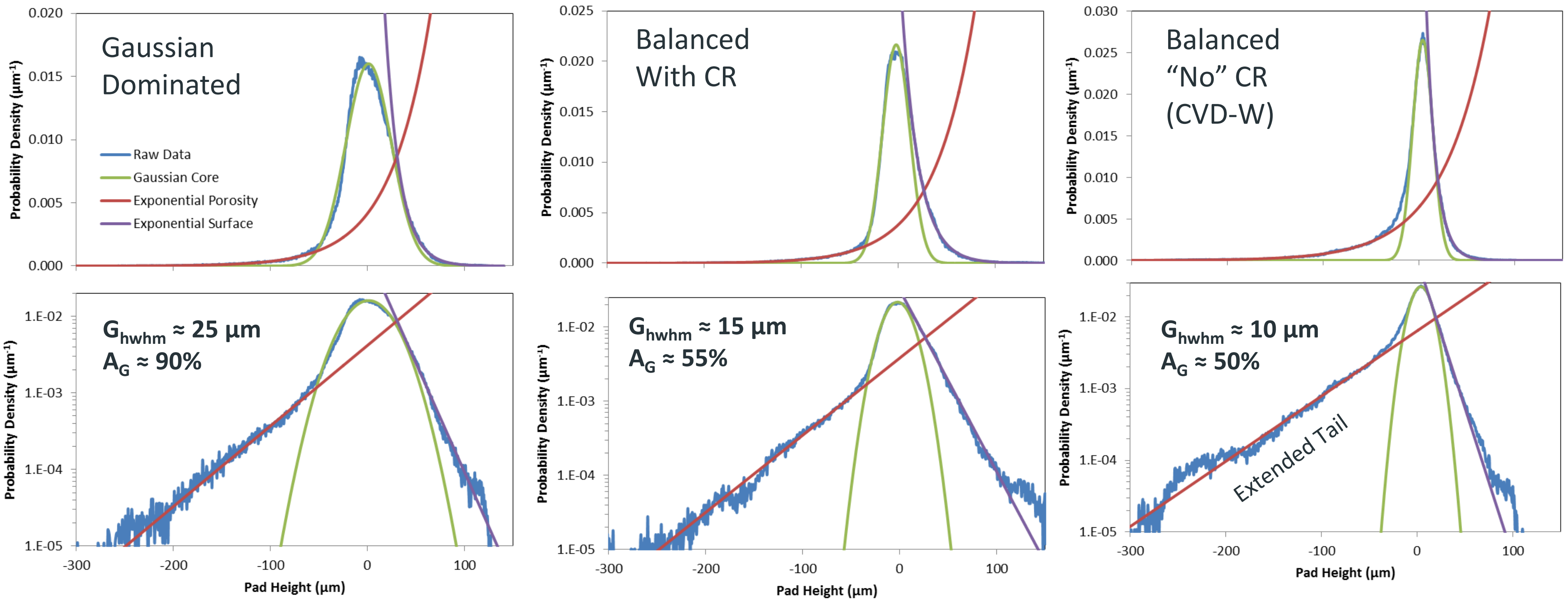
- The diamond conditioners screened all exhibited similar cut rates
- The brush and CVD-W conditioners exhibited cut rate below the measureable threshold

Pad Height Data from Conditioning Matrix



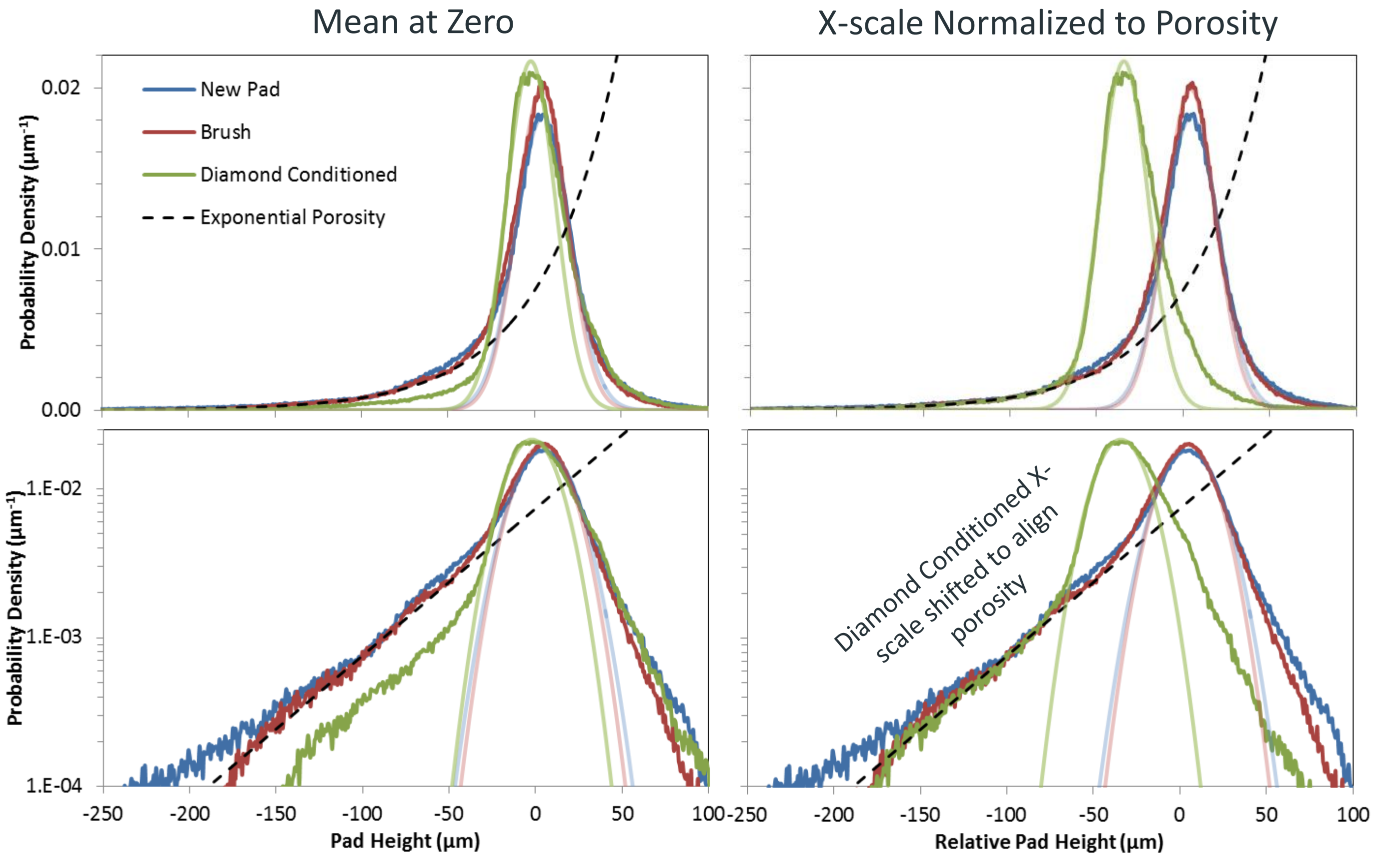
- **Pad height distributions can be split into 3 broad groups**
  - **Pads with no cut rate**
  - **Pads with cut rate**
    - **Pads with a primarily Gaussian texture**
    - **Pads with a "balanced" texture**
- **Pads with no cut rate have a deeper pore structure (≈ 50 µm)**
- **Gaussian core roughness can be driven across a wide range, incorporating the typical as received roughness and expanding the potential roughness space**
- **The exponential porosity signature of the pad is very consistent but on conditioned pads represents < 5% of the total distribution**
- **Many of the conditioned pads exhibit a kind of "stretched" or "distorted" core structure**
  - **Possibly an artifact of the HCR tester?**

Example Pad Height Distributions



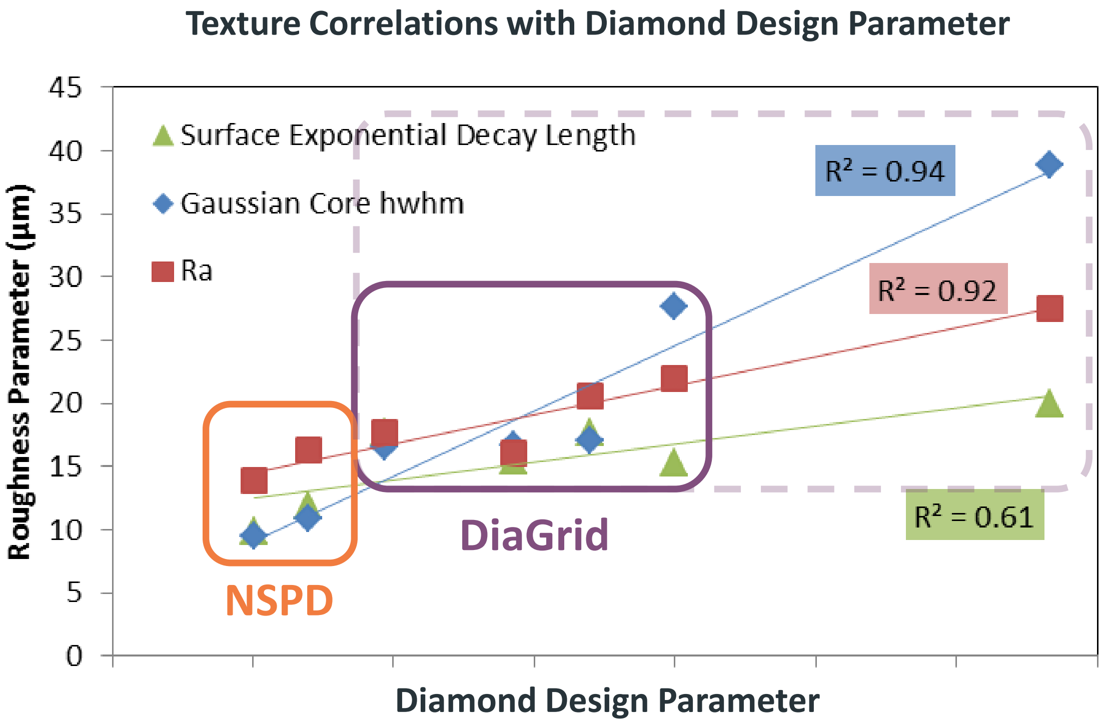
- **Diamond conditioning can drive pad roughness over a wide range**
- **The Gaussian core dominates the distribution at higher**
- **A CVD-W treatment imparts a smoother near surface while exhibiting minimal cut rate**

Brush vs. Diamond Conditioning



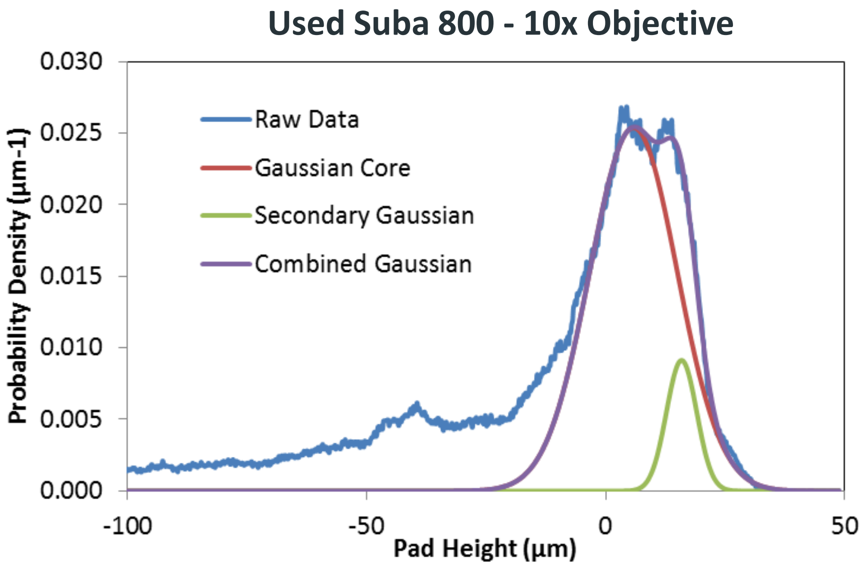
- **The brush conditioned surface is nearly identical to the new pad surface**
  - **Measured Cut Rate is negligible with a brush**
- **A diamond conditioned pad with similar core roughness exhibits a shallower pore structure (but with the same decay constant) and a relative shift in the position of the Gaussian core**
- **This implies that a brush is not capable of establishing or regenerating pad surface texture**

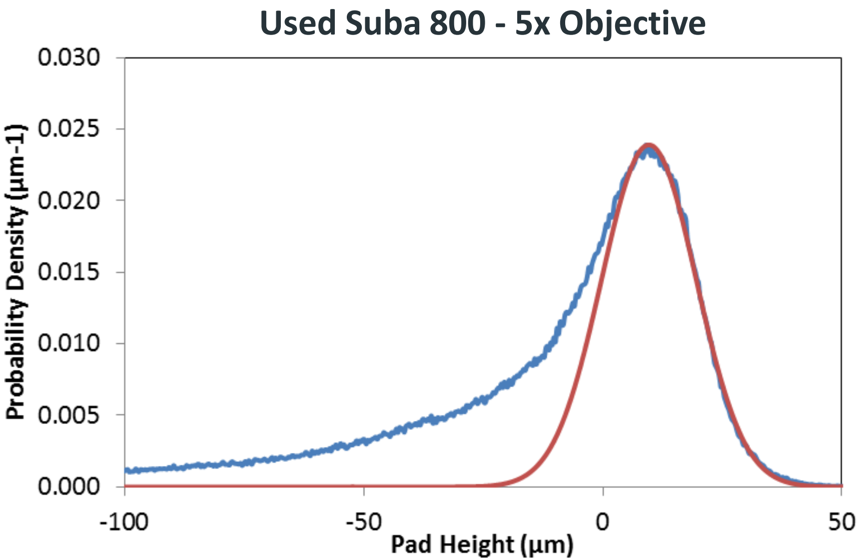
Suba 800 Conditioning Response



- For conditioned pads, multiple defining textural parameters are strongly correlated with a basic design parameter, indicating a well-behaved and predictable conditioning design space, as well as the ability to drive texture over a wide range
- Kinik DiaGrid conditioner designs widely used in semiconductor CMP applications cover the typical range of core roughness
  - We are actively expanding this range with product improvements
- Kinik NSPD conditioners develop smoother textures
- CVD-W designs can impart lower roughness with low or negligible cut rate

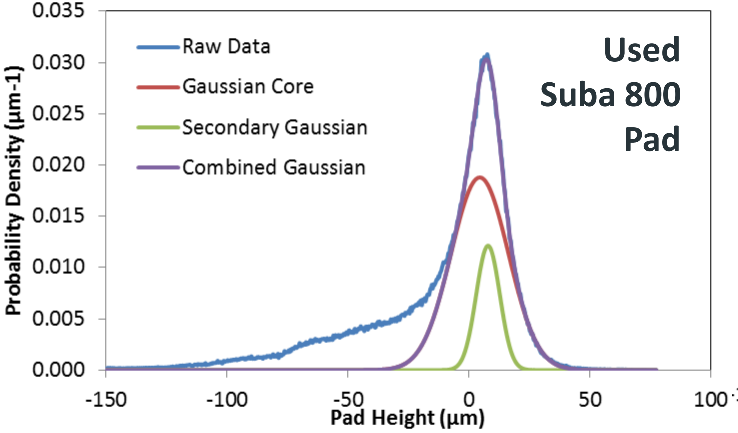
Polishing Effects on Type 1 Pads

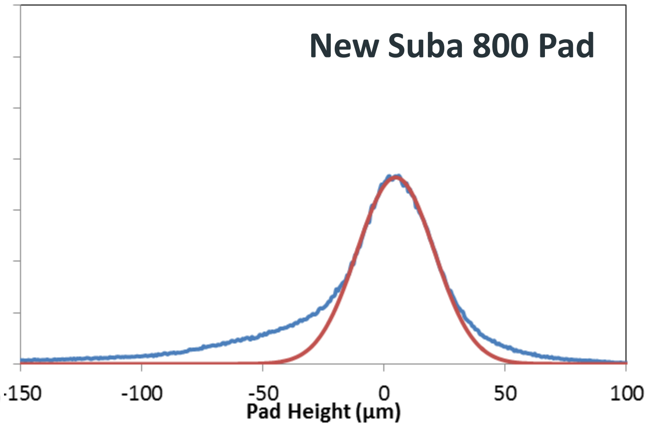


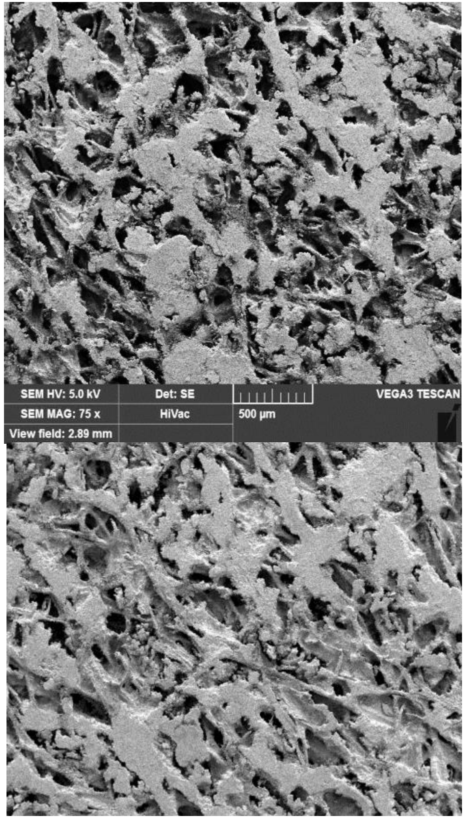


- **Surface signatures that look like asperity truncation can be seen on Type 1 surfaces, but they are difficult to quantify**
  - **The same pad area may show a distinct doublet that gets "washed out" when sampling a larger area**
- **Note the noisier response in the roughly 4x smaller sampling area with the 10x objective**

Polishing Effects on Type 1 Pads







- Surface signatures like this are more common, where there is clearly deformation (note the substantially higher amplitude in the used pad probability density) and the best fit represents a superposition of two Gaussian modes (one of which is similar to the new pad core roughness), but without a clear doublet or shoulder
- Flattened looking surface structures are typically observed in SEM images, accompanying the distortions in the surface statistics

Summary

- Type 1 pad texture follows similar Exponential-Gaussian statistics to Type 3 pads
  - The porosity of Type 1 pads can be modeled as an exponential
    - The signature (decay constant) of the exponential is a function of fiber/impregnation
    - Less impregnated pads have a deeper pore structure
  - A Gaussian core component can be superimposed on the native porosity
    - With conditioning, core texture can be driven across a range that includes the core roughness of new pads
  - A secondary Exponential component is generally seen at the near surface
  - Core roughness of new pads varies based on buffing treatment
  - Glazing phenomena have been observed
- Textures significantly smoother than new pads can be obtained with or without significant cut rate
- Pad surface analysis of used pads indicates an opportunity for improved conditioning protocols in the processes utilizing these pad types
  - Used pads inevitably have the majority of their thickness remaining
- The ability to engineer surface texture through pad conditioning as not been widely investigated on these pads and may provide significant process leverage