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”

• 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
Accurate determination of the porosity distribution can provide the basis for specification of “compatible” conditioning protocols.

The characteristic decay length of the exponential ($\tau$) 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.

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

Slide courtesy of Dow (now DuPont Electronics and Imaging)
Conditioning Induced Roughness

- 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

- 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**

- **EMG definition:**
  \[ f(x; h, \mu, \sigma, \tau) = \frac{h\sigma}{\tau} \sqrt{\frac{\pi}{2}} \ast \exp\left(\frac{1}{2} \left(\frac{\sigma}{\tau}\right)^2 - \frac{x - \mu}{\tau}\right) \ast \text{erfc}\left(\frac{1}{\sqrt{2}} \left(\frac{\sigma}{\tau} - \frac{x - \mu}{\sigma}\right)\right) \]
  - 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 \(\sigma\) of an independent Gaussian except at very low values of \(\tau\)
  - EMG was developed for chromatography but provides an excellent description in cases where there is a smooth transition between the \(E\) and \(G\) components

**Poor EMG Fit**

- **De-coupled Exponential/Gaussian**
  - The de-coupled model treats each component independently, providing greater flexibility
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.
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
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.

Suba 800

- $G_{\text{hwhm}} \approx 15 \, \mu m$
- $A_G \approx 60%$
- $\tau \approx 40-45 \, \mu m$
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
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?

- Exponential porosity from combined new pad data set ($\tau = -43.41 \, \mu m$)
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

Gaussian Dominated

Balanced With CR

Balanced “No” CR (CVD-W)

$G_{hwhm} \approx 25 \mu m$
$A_G \approx 90\%$

$G_{hwhm} \approx 15 \mu m$
$A_G \approx 55\%$

$G_{hwhm} \approx 10 \mu m$
$A_G \approx 50\%$

Extended Tail
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
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