CMP KNOWLEDGE FOUNDRY AND BIG DATA ANALYTICS



A. Philipossian, N. Monfared, Y. Sampurno, and J. J. Keleher

ARACA INCORPORATED

The Polishing and Planarization Experts

Araca, Inc., 2550 East River Road, Suite 12204, Tucson AZ 85718 USA www.aracainc.com

Outline

- Unique single-platen polishers by Araca that enable digital transformation.
- Polisher simple input and output parameters.
- Polisher complex input and output parameters.
- Examples of three real-life polishing tests and the richness of data obtained.
- The "Easy" approach to data interpretation and reporting vs. "Deep Diving" to gain insight.
- The Planarization Knowledge Foundry[®]
- Digital transformation through Araca Insights[®]
- Several examples of data analytics.
- Summary.

Unique Polishers that Enable Digital Transformation

- Araca's single-platen CMP polishers and tribometers for R&D:
 - **APD-800X**® (200 and 300-mm wafers)
 - ***** RDP-500[®] (100, 150 and 200-mm wafers)
- Manufactured in Japan by Fujikoshi Machinery Corporation (a major Araca shareholder) under our brand name.
- Unique, highly-sensorized systems with advanced data capture and analyses functions by Araca (FSX-800X® and FSX-500®). Can measure high-frequency shear and down forces in real-time, acquire and analyze real-time fluid dynamics and thermal data (among other things).
- Matched 1-to-1 to AMAT polishers in terms of platen and carrier sizes, tool kinematics, independent wafer and ring pressures and designs, as well as disc dwell times and conditioning zones.



APD-800X® "Simple" Process Parameter Inputs and Outputs

APD-800X®

Platen Velocity Carrier Velocity Disc Velocity Disc Downforce Ring Pressure Disc Position Wafer Downforce 1, 2, 3, and 4

Conditioning Scheme – Ex-situ, insitu or mixed Pad Type – A, B or ... Slurry Type – A, B or ... Disc Type – A, B or ... Ring Type – A, B or ... Slurry Type – A, B or ... Polish Time – A, B or ... Flow Rate – A, B or ... Wafer Size – 200 or 300 mm Wafer Type – As-received or Prepolished Film Type – Cu, ILD, W, Ta, TaN or ... Pad Break-In Time – A, B or ...



Shear Force Effective Normal Force Pad Surface Temperature Platen MC Carrier MC Conditioner MC

Initial Film Thickness Profile Final Film Thickness Profile Dishing at L1, L2, and L3 Erosion at L4, L5, and L6 Pad-Wafer Contact Area Percentage Contact Density Mean Asperity curvature Mean Asperity Height Abruptness Factor



Quantitative Parameter measured in-line at 1,000 Hz

Qualitative Parameter

Quantitative Parameter measured off-line

APD-800X® "Complex" Process Parameter Inputs and Outputs

APD-800X®

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Pad-Wafer Relative Sliding Velocity Effective Wafer Pressure

Coefficient or Friction Power Density Variance of Shear Force Variance of Normal Force Directivity Pseudo-Sommerfeld Number

Amount of Film Removed vs. Radial Location Average Removal Rate Average Within-Wafer RR Non-Uniformity



Quantitative Parameter measured in-line at 1,000 Hz Quantitative Parameter measured off-line

Two Real-Life Slurry-Related Examples from 2020 and 2021

- Copper-Barrier slurry tests requested by Supplier A:
 - 14 different slurry formulations
 - 5 types of wafers (i.e., Ta, TaN, PE-TEOS SiO2, BD and copper)
 - ✤ 6 PV combinations

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- Took us 3 weeks to complete all tests
- Tungsten slurry tests requested by Supplier A:
 - 9 different slurry formulations
 - 2 types of wafers (i.e., W and PE-TEOS)
 - 9 PV combinations
 - 3 polish times
 - 2 wafer types (i.e., as-received and prepolished)
 - ✤ 2 wafer suppliers
 - 2 initial tungsten film thicknesses (i.e., 2KA and 6KA)
 - Pad microtexture
 - Took us 6 weeks to complete all tests

No. of High-Frequency In-Line Data Collected > 600MM

> No. of Off-Line Data Collected > 300K

No. of High-Frequency In-Line Data Collected > 200MM

> No. of Off-Line Data Collected > 2MM

A Real-Life Disc Experimental Examples from 2021

- Copper disc tests requested by Supplier B:
 - 9 different disc types
 - 2 types of wafers (i.e., Cu and PE-TEOS)
 - 12 PV combinations
 - Pad microtexture
 - Took us 4 weeks to complete all tests



Collected > 1MM



How Have We Dealt With This So Far?

- When faced with > 100MM data points, human nature's first tendency is to average things.
- This provides some useful information and trends And it is just about all one can do without breaking the bank – So far, this is how we've reported data to our customers!



Examples of Critical Information that Gets Lost in Averaging



Lost Information – Sometimes we see "Hidden" Orbits!



Planarization Knowledge Foundry®



We are creating an experimental network of Copy <u>EXACTLY</u>! tools and methodologies with Lewis University and three <u>exclusive</u> long-term <u>Strategic Partners (SP)</u> at an affordable price!

Through such a "triangulation", we will begin to create an exclusive "Global CMP Knowledge Foundry" for our slurry, disc and pad strategic partners!

Looking to replicate the model with a PVA brush supplier and a retaining ring supplier.

Planarization Knowledge Foundry®

- In the next 3 to 9 months, we will:
 - Together with one of our SPs, speed up the screening and development of novel CMP and post-CMP cleaning consumables.
 - Enable the SP to independently characterize the tribological, thermal and kinetic attributes of myriad consumables and processes.
 - Standardize the way CMP knowledge is acquired, reported and used – We will converge on a common language!
 - Have processes that are easily portable to HVM polishers.











DATA **# KNOWLEDGE # INSIGHT**

> 95 percent of all data generated by our polishers and cleaners is "DARK MATTER"!

Araca Insights[®] helps our strategic partners bring more data to light, put robust systems in place for centralized R&D data banking, management, analyses, and modeling.

- Main Challenge Too much data from too many instruments gets generated during a set of CMP experiments:
 - Polisher
 - Post-CMP cleaner
 - Blanket wafer film thickness metrology tools
 - Blanket wafer defect metrology tools
 - Patterned wafer topography metrology tools
 - Pad microtexture analyses tools
 - In-line slurry health monitoring tools
 - Others

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Quantitative Parameter measured in-line at 1,000 Hz

Qualitative Parameter

Quantitative Parameter measured off-line

- On the **STORAGE** side of things, our software provides:
 - Highly-organized central data center containing all of the data gathered from various tools in an easy-to-access format with a descriptive file nomenclature.
 - Highly secure storage service with double authentication access for users.
 - Automatic storage of newly collected data in our cloud servers.
 - ***** Automatic QC of newly collected data.
 - Automatic notification to the user when data is uploaded to servers.
 - ***** Automatic parallel storage and backups for each single set of data.
 - Parallel uploads from different centers (i.e., Araca, Lewis University, and strategic partners).
 - Easy cross-regional access to the data collected by other centers with low latency
 - Elastic and scalable expansion of centers as the amount of metrology tools or knowledge foundry centers increase.
 - 1:10,000,000 durability (i.e. only 1 file per 10MM might get lost)

- On the **ANALYTICS** side of things, our software provides:
 - Recognition of data types, data cleaning, anomaly detection and QC of data.
 - ✤ Automatic aggregation of required properties to be easily accessed.
 - Ability to filter test properties to reach tests done in the same category (i.e. copper or STI)
 - Interactive live-selection and visualizing of required property relations within desired ranges.
- On the GUI side of things This is work in progress with our BETA version available in January 2022.
- Al and ML Longer-term activities depending on general sentiment and customer feedback 2022 or 2023!

Araca Insights[®] – Example Output – Cu CMP



Evolution of Polar Asymmetry in CMP – B. Zhang – CAMP – 2021

- Polar asymmetry in RR:
 - A wafer edge effect (not the interior of the wafer)
 - Not related to non-uniform distribution of film stress or film density
- Factors influencing polar asymmetry in RR:
 - Hardware (head)

Fy (N)

- Kinematics
- Pressure
- Consumables
- Polish time



Araca Insights[®] – Example Output (20 to 26 sec) – Cu CMP







Closing Thoughts

