NOZZLE HARDWARE FOR SLURRY REDUCTION DURING CMP

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INTRODUCTION

Chemical Mechanical Planarization (CMP) process comprises of pads, conditioner disks, slurry, head, and cleaner consumables. Reducing cost of individual sub-components will have significant impact on Cost of Consumables (CoC) and Cost of Ownership (CoO) for customer[1]. Traditional drop location for most CMP processes (Process on Record) is the center of the pad and slurry flow rates (SFR) are usually in the 200-300 mL/min range. As shown in Figure 1a, majority of the slurry hits the rotating head or spins off the platen due to centrifugal force. This results in significant wastage and minimizing it by reducing slurry consumption, will help reduce slurry cost/CoC by 30-50%. Additionally, with POR slurry drop location and low SFR, pad damage (Fig 1b) was observed for certain consumable sets under certain polish conditions. Figure 2a illustrates CoC and slurry cost benefit that can be achieved, for ceria-based slurry, with reduced slurry usage. By reducing SFR by 50%, nearly 30% reduction in CoC can be achieved. Figure 2b highlights normalized cost comparison between slurry used for DRAM, STI and Oxide buff processes.

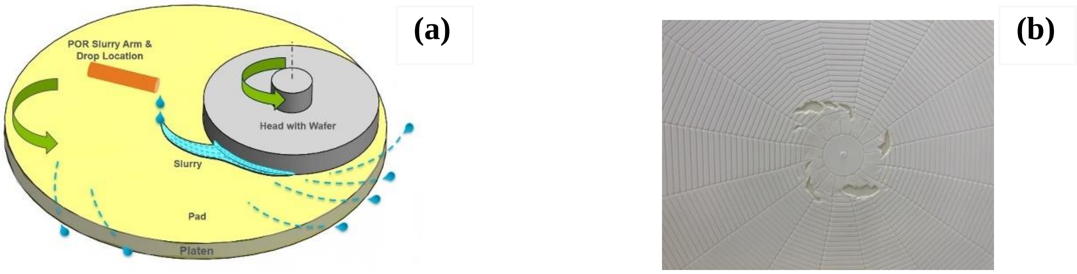


Fig.1a: Slurry wastage observed with POR CMP process. Fig.1b: Illustrates pad damage observed for certain consumable sets at low slurry flow rates and with drop location at the center of the pad.

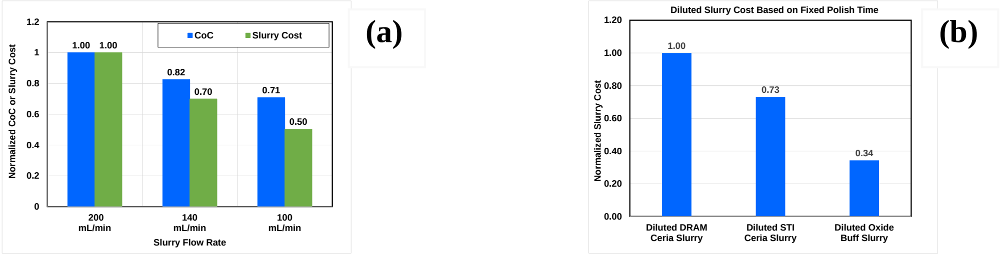


Fig.2a: Graph illustrates CoC and slurry cost benefit achieved with reduced slurry usage. Figure 2b shows normalized cost comparison between ceria slurries used for DRAM/STI processes and Oxide Buff Slurry.

As show in Figure 3 a prototype non-contact nozzle hardware (NH) has been developed on Applied Reflexion LK™ Prime system to enable reduced slurry consumption and efficient distribution at low SFR. The prototype Nozzle Hardware (NH), comprising of 3 nozzles (Front, Middle, Base) placed strategically across the pad surface, was designed and initial testing with ceria and silica-based slurries have been completed. An advanced flow modulation system was used to control frequency and duty cycle of the nozzles. The hardware enables flow rate modulation and efficient delivery at SFR as low as 40 mL/min.

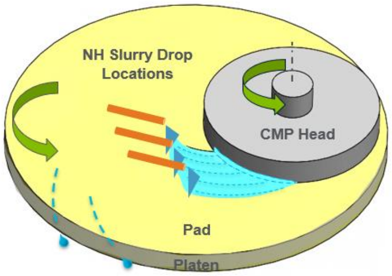


Fig.3 Nozzle Hardware (NH) comprising of nozzles placed strategically across the pad surface for efficient coverage. Advanced flow modulation can be used to control frequency and duty cycle of the nozzles.

EXPERIMENTAL

Blanket Thermal Oxide and TeOS wafers were polished with POR slurry delivery and Nozzle Hardware (NH). Wafers were polished on industry standard consumable set (pad/disk) and diluted high selective ceria slurry. Recent experiments were also completed with silica-based oxide buff slurry. Blanket oxide removal rate was monitored on both thermal oxide and TeOS wafers. Wafer were polished at 2psi, 60-145rpm, with ex situ pad conditioning at 6lbf. Post polish wafers were measured using a 116 and 761 - points blanket metrology recipe. Post-CMP defect performance was also evaluated on TeOS wafers that were cleaned using Applied Materials Cleaner BKM chemistry.

DISCUSSION

Figure 4a & 4b illustrates normalized rate for thermal oxide & TeOS wafers at different flow rates (High = H, Medium = M, & L = Low slurry flow). Medium & Low flow represents 50-75% reduction in SFR compared to POR (H) flow rate. Results indicate that the blanket oxide rates with nozzle hardware rates are comparable to POR process. Recent experiments with silica-based oxide buff slurry indicates that nozzle hardware results in 40% reduction in slurry usage at low and intermediate flow rates. Slurry flow levels for silica slurry was L < M2 < M < H. Pad temperature data shown in Figure 5 indicates that process with nozzle hardware has slightly lower temperature compared to POR process.

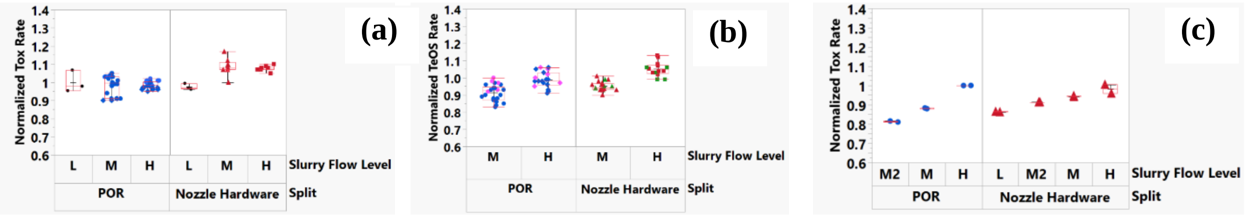


Fig.4 (a & b) Normalized oxide removal rate comparison at different slurry flow levels for POR vs. Nozzle Hardware (NH) process using ceria slurry. Fig 4c: Normalized oxide removal for silica buff slurry.

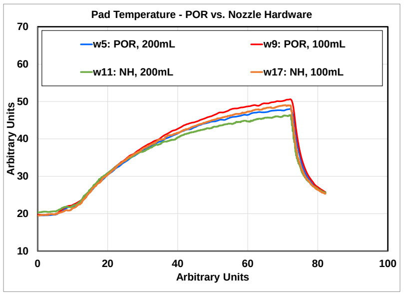


Fig.5: Pad temperature comparison between POR vs. Nozzle Hardware Process. Pad temperature for Nozzle Hardware (NH) is slightly lower compared to POR process.

Blanket TeOS defect wafers processed using POR and NH were cleaned using Applied BKM Cleaner Process. Fig. 6a shows that Chem 2 has much better blanket defect performance compared to Chem 1. Post CMP scratch analysis was performed using Applied's SEMVision™ tool. Fig. 6b indicates that scratch performance for NH is comparable to POR process.

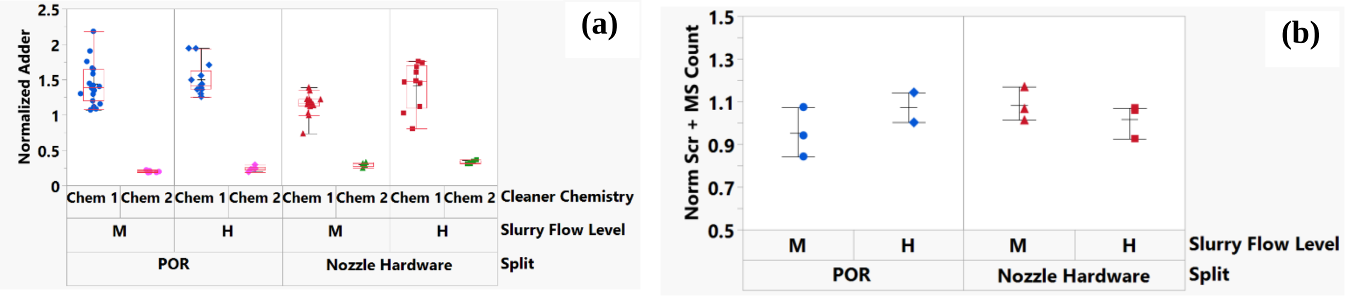
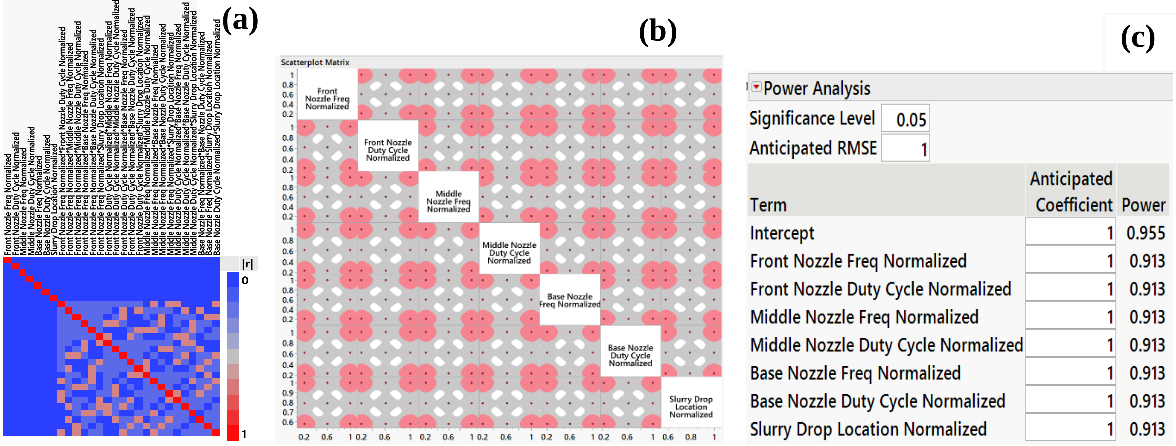


Fig 6a & 6b: Graph illustrates blanket defect performance for POR and NH process with Medium and High slurry flow rates. Defect performance for NH process was found to comparable to POR process.

DESIGN OF EXPERIMENT

The nozzle hardware was further characterized, for its capability to reduce slurry usage, using statistics-based design of experiments. Building regression model and optimization allows for experimentation with minimal material usage. It is critical to explore full design space to find optimal operating conditions and understand parameter sensitivity that can be leveraged for design iteration[2]. The process starts with defining the voice of customer, followed by translating it into system and component level functional, design, and hardware requirements. A parameter diagram is developed to map design parameters, signal, and noise sources in the system under evaluation. For the nozzle hardware, design parameters identified were nozzle duty cycles, frequency, and slurry drop location while the rest of system parameters were kept fixed at nominal values. The operating ranges for these parameters were chosen such that a quadratic regression model can be built in the data collection window. Definitive screening design of experiment (DOE) was used to generate a DOE matrix in which first order parameters are fully orthogonal with the two parameter interactions as shown in Fig 7(a). The DOE matrix also uniformly covers the entire operating space as shown in Fig 7(b) which allows to fit a second order model in the entire operating space. The significance level (alpha) of the DOE was 0.05 to build a model with 95% confidence and the DOE also has high probability of parameter effect detection (>0.9) as shown by power analysis in Fig 7(c)



Power Analysis

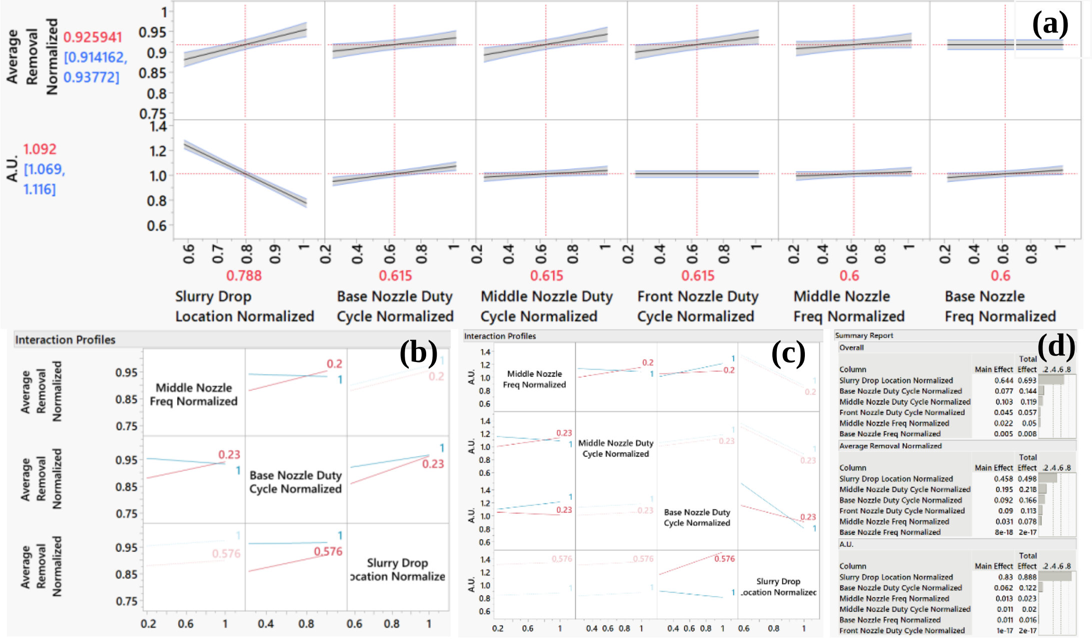
Significance Level 0.05

Anticipated RMSE 1

Term	Anticipated Coefficient	Power
Intercept	1	0.955
Front Nozzle Freq Normalized	1	0.913
Front Nozzle Duty Cycle Normalized	1	0.913
Middle Nozzle Freq Normalized	1	0.913
Middle Nozzle Duty Cycle Normalized	1	0.913
Base Nozzle Freq Normalized	1	0.913
Base Nozzle Duty Cycle Normalized	1	0.913
Slurry Drop Location Normalized	1	0.913

Fig 7(a) Color map of correlations showing that all the first order parameters are fully orthogonal to the two parameter interactions 7(b) Scatterplot matrix showing data points with corresponding parameter levels collected in this experiment 7(c) Power analysis table showing the significance level and statistical power analysis indicating the probability of detection of parameter's effect

The experimental data was collected for DOE matrix shown in Fig 7(b) and two second order parsimonious response surface models were fitted for removal rate and on-wafer non-uniformity. First order effects and two parameter interactions were found to be statistically significant with p-values < 0.05. However, none of the quadratic effects were found to be statistically significant within the operating window. The cross-section profiles of response surface model's main effects and two factor interactions are shown in Fig 8.



Summary Report

Overall

Column	Main Effect	Total Effect
Slurry Drop Location Normalized	0.644	0.693
Base Nozzle Duty Cycle Normalized	0.077	0.144
Middle Nozzle Duty Cycle Normalized	0.103	0.119
Front Nozzle Duty Cycle Normalized	0.045	0.057
Middle Nozzle Freq Normalized	0.022	0.05
Base Nozzle Freq Normalized	0.005	0.008

Average Removal Normalized

Column	Main Effect	Total Effect
Slurry Drop Location Normalized	0.458	0.498
Middle Nozzle Duty Cycle Normalized	0.195	0.218
Base Nozzle Duty Cycle Normalized	0.092	0.166
Front Nozzle Duty Cycle Normalized	0.09	0.113
Middle Nozzle Freq Normalized	0.031	0.078
Base Nozzle Freq Normalized	8e-18	2e-17

A.U.

Column	Main Effect	Total Effect
Slurry Drop Location Normalized	0.83	0.888
Base Nozzle Duty Cycle Normalized	0.062	0.122
Middle Nozzle Freq Normalized	0.013	0.023
Middle Nozzle Duty Cycle Normalized	0.011	0.02
Base Nozzle Freq Normalized	0.011	0.016
Front Nozzle Duty Cycle Normalized	1e-17	2e-17

Fig 8(a) Combined first order profiles of design parameters for removal rate and non-uniformity, (b) Two parameter interaction matrix for removal rate, (c) Two parameter interaction matrix for non-uniformity, d) Sensitivity analysis shows overall sensitivity, removal rate and non-uniformity.

The sensitivity of design parameters was derived using Analysis of Variance (ANOVA) method by combining each parameter's main effect and interaction contribution shown in fig 8d. Slurry drop location is a dominant parameter for removal rate and non-uniformity. CMP process is a combination of chemical and mechanical interaction between the slurry, pad, and wafer surface. The DOE results support this core mechanism and highlights the role slurry distribution plays in film removal and uniformity. Interaction between nozzle parameters highlight the importance of controlling slurry flow in specific regions of the pad surface. The results also indicate that minimal amount of slurry is required to get the desired film removal while maintaining defect performance.

CONCLUSIONS

Nozzle Hardware provides ability to reduce SFR & enables uniform distribution and flow modulation across pad surface. Blanket removal and defect performance for Nozzle Hardware rate are comparable to POR process for ceria process. For silica slurry, nozzle hardware results in 40% reduction in slurry usage. DSD DOE indicates that slurry drop location is the dominant factor for wafer profile modulation.

REFERENCES

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