Slurry Use Minimization for STI CMP by Motor Current Endpoint Detection

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Driving Force

Endpoint detection of STI CMP has chronically been difficult to successfully implement on an industrial scale.

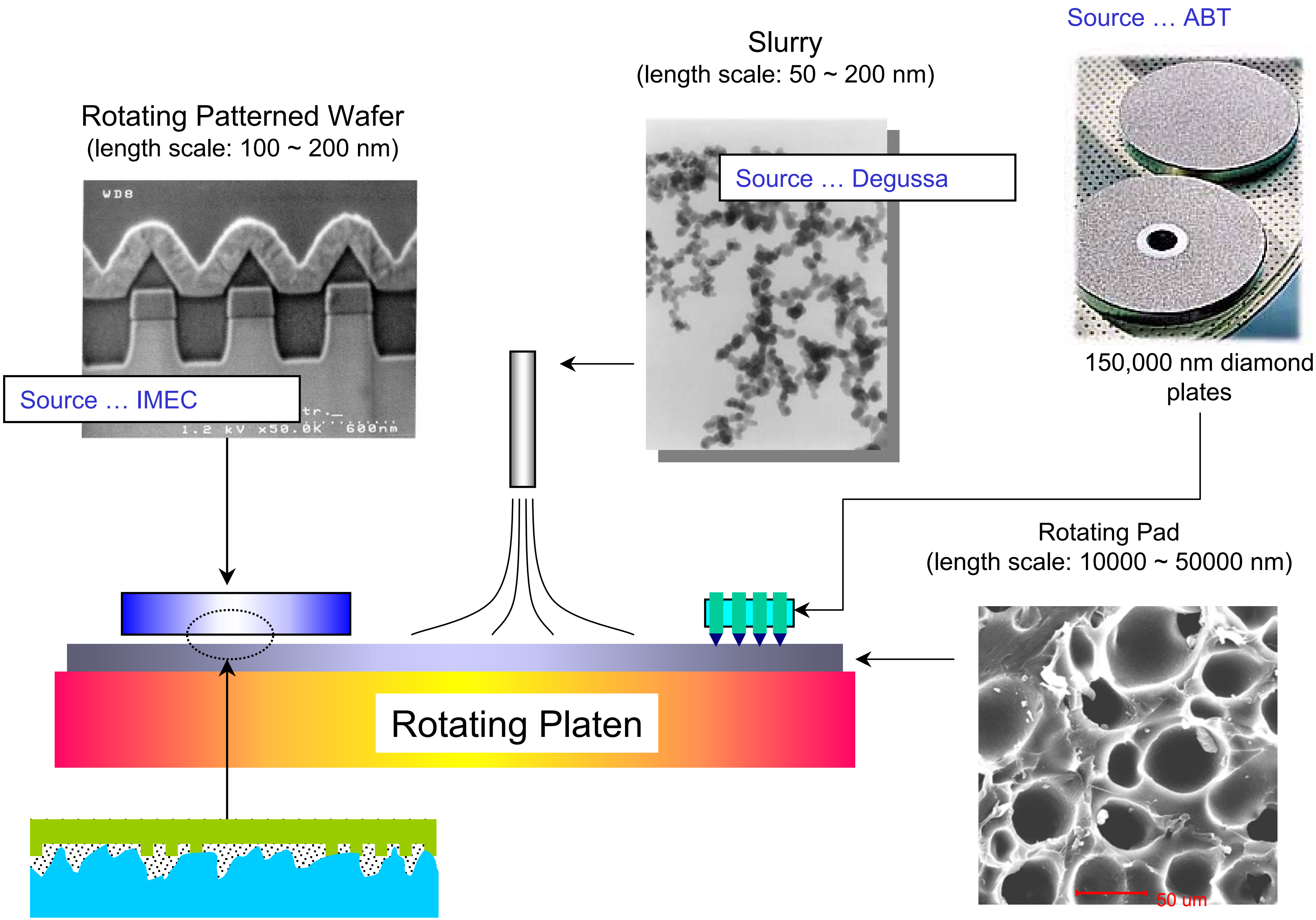
Endpoint detection can not only improve product quality, but it can also minimize slurry use

This study aims to qualify motor current endpoint detection for STI wafers of various pattern densities. Based on the accuracy and duration of the endpoint technique, this study will evaluate the potential impact on slurry minimization during CMP.

Understanding these effects could lead to the development of new environmentally benign polishing methods for STI CMP

This can also result in more efficient slurry and pad usage for existing processes

Generalized Schematic of CMP



Background

- Endpoint detection is an in-line method of determining the termination point of wafer polishing based on metrological (i.e. film thickness) or physical (i.e. tool hardware) signals obtained during the CMP process

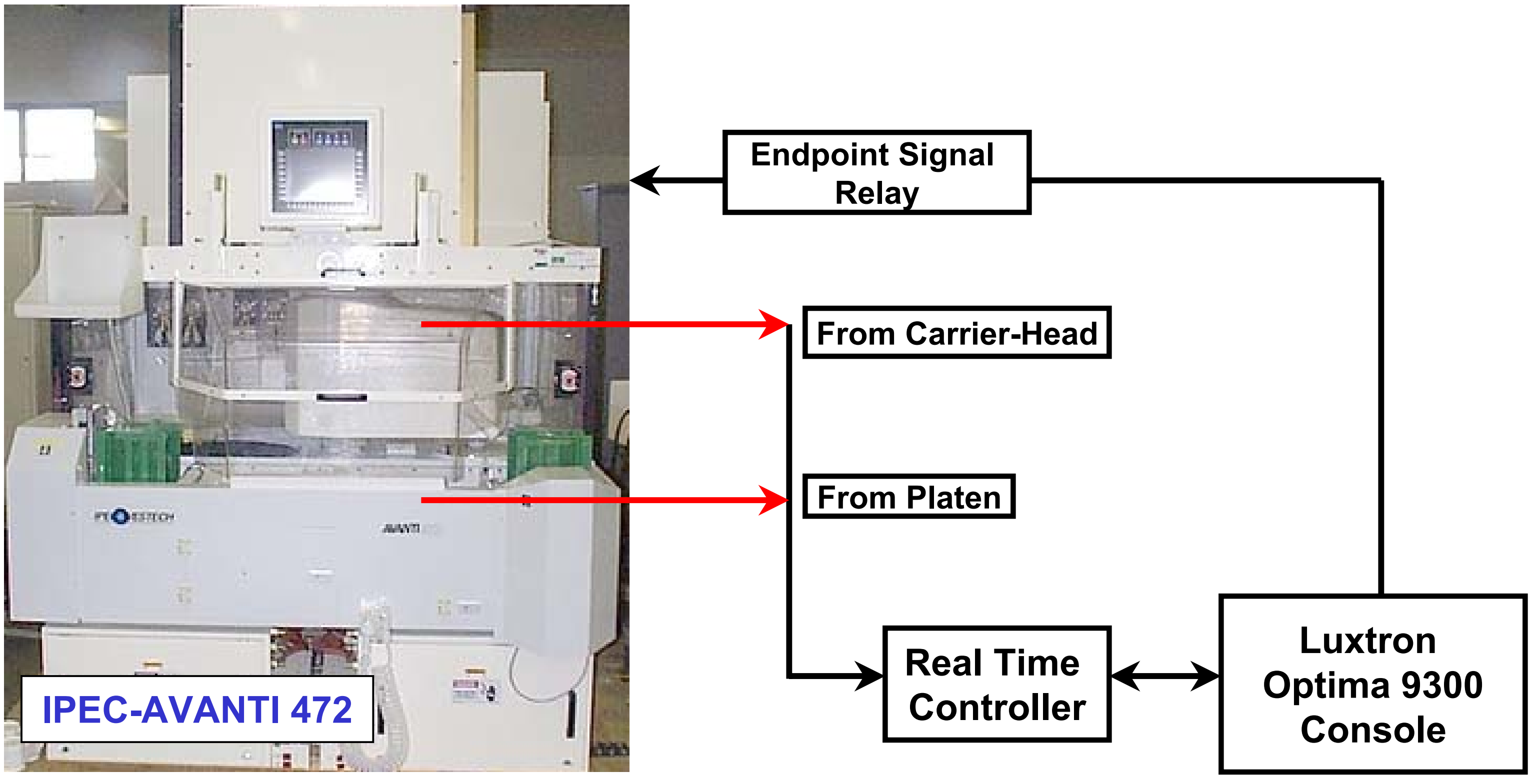
- Endpoint detection is achievable through many methods
  - Optical – Most common method for STI endpoint detection
    - Issues include false detection as a result of diffraction and scattering effects caused by wafer movement over the detector and light source
  - Thermal – Most commonly used for metal CMP
    - Unsuccessful for STI CMP due to the lack of a characteristic thermal signal during polishing
  - Acoustic – Novel method based on sensing vibrations resulting from variations in wafer topography
    - Unsuccessful for STI CMP due to signal noise/sensitivity and weak signal upon reaching barrier nitride level

Background

- Continuation of endpoint detection methods:
  - Electrochemical – Involves detecting differences in electrochemical potential of either slurry or wafer film with respect to a reference electrode
    - Dielectric layers of STI substrates lack of electrochemical characteristics thus eliminating possible application of method
  - Motor Current (Frictional) – Based on the monitoring of platen and carrier-head output currents
    - Various frictional effects are generated resulting from wafer patterns, wafer pattern densities, and film materials
    - Potential application for STI CMP is high due to characteristic frictional signals generated by shallow trench patterns and densities

- Previous motor current endpoint detection studies for STI CMP have shown issues associated with extraneous noise from conditioning and tool hardware

Integrated Endpoint Polishing



- Motor Current signal range – 2mA to 25A
- Signal frequency – 10 Hz

Experimental Parameters

- **Constants**
  - **Pad**
    - Rodel IC-1400 K-groove pad
  - **Break-In**
    - 100 grit diamond disk
    - 4 sweeps at 5 PSI
  - **Slurry**
    - Cabot D7300 at 225 cc/min (12.5% wt.)
  - **Conditioning**
    - Ex-situ at 4 sweeps between polishes
  - **Wafer Pressure**
    - 7 PSI (backpressure = 0.2 PSI)
  - **Polishing Speeds**
    - Carrier-head – 32 rpm
    - Platen – 28 rpm
  - **Buffing Stage**
    - 30 seconds with ultra-pure water
    - 5 PSI
    - Fujimi-SSW1 pad

Experimental Parameters

- **Variables**
  - **Wafer Types (150-mm)**

Wafer Set	Oxide (%)				Nitride (%)		Trench Depth (Å)	TEOS Trench Fill (Å)
	Density Variation	Max	Min	Mean	Density Variation	Mean		
A	13.8	19.4	5.6	11.7	95.8	36.2	5000	9000
B	17.4	26.4	9.0	19.0	35.5	28.4	5000	9000
C	15.9	30.7	14.8	24.3	59.1	41.3	3100	5900
D	25.2	48.4	23.2	37.3	62.2	41.4	3100	5900

- **Phases**

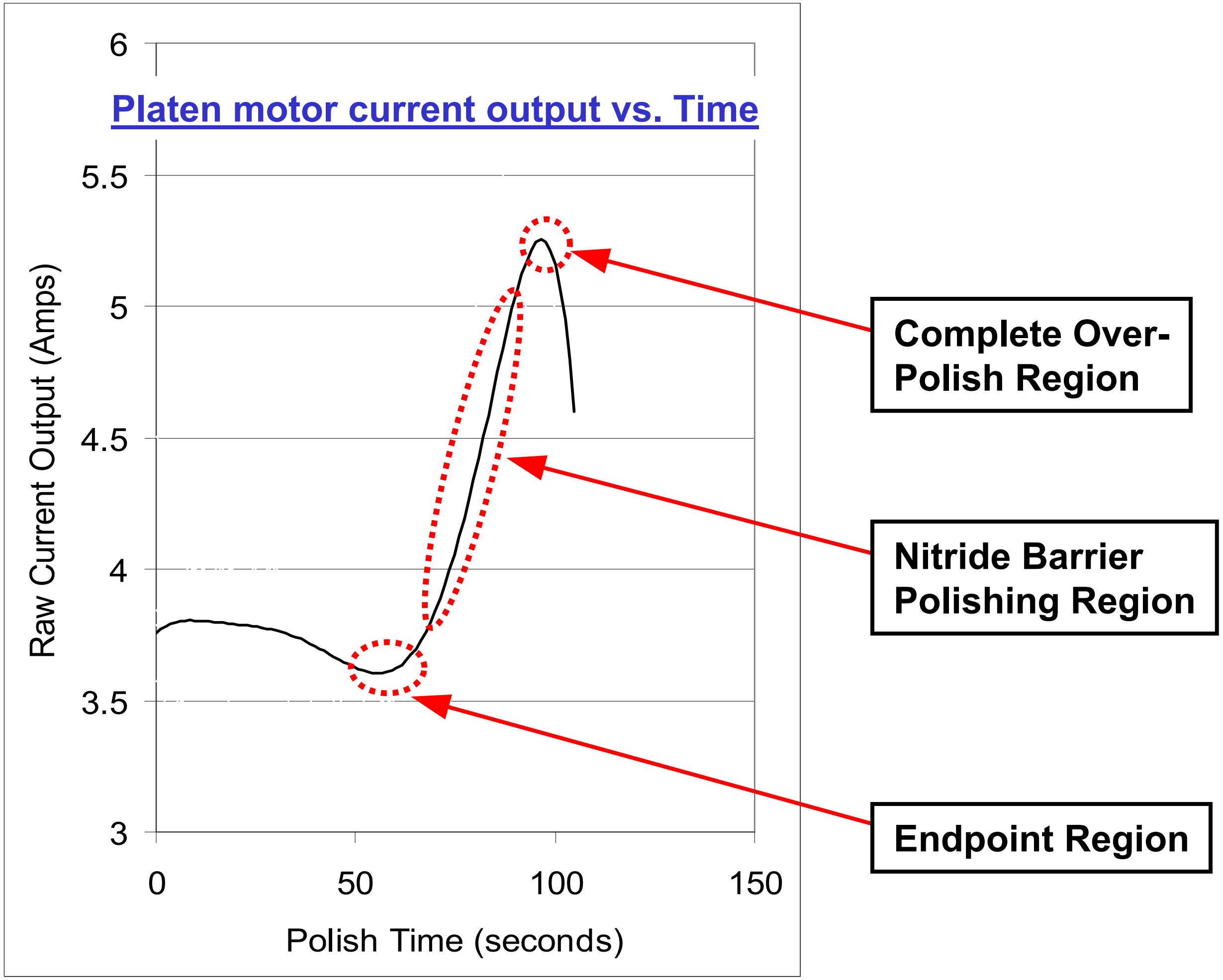
I. **Characteristic endpoint profiling**: **Complete over-polish to determine the overall signal obtained for each wafer pattern under typical polishing conditions**

II. **Timed endpoint accuracy:** **Timed polishes to establish approximate point at which endpoint should be triggered**

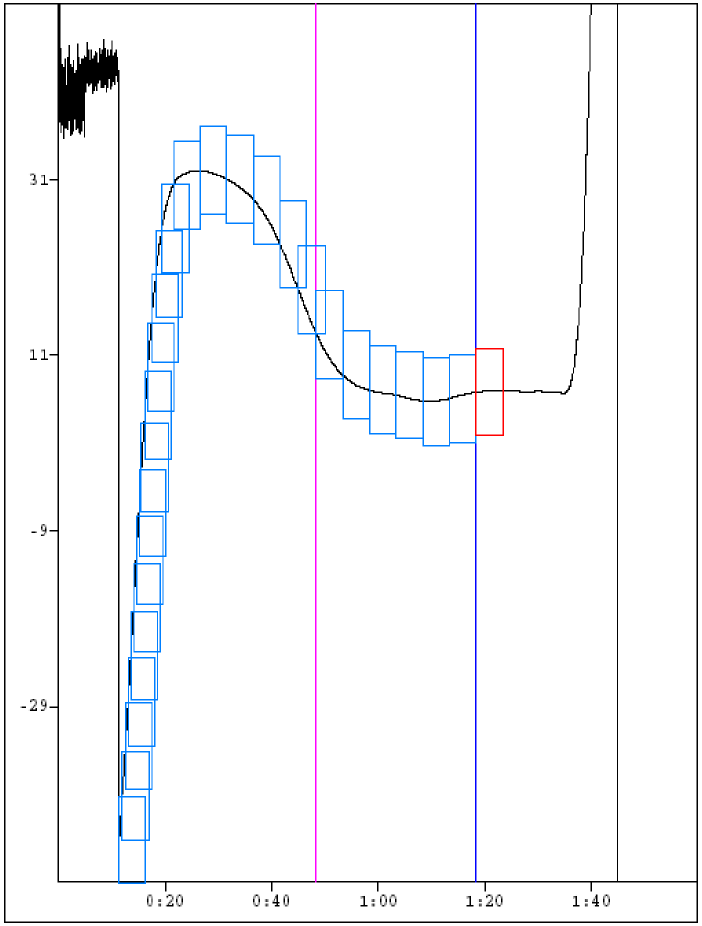
III. **Endpoint recipe validation:** **Evaluation of the validity and functionality of patterned wafer polishes using endpoint recipe from Phase II**

Phase I: Complete Endpoint Signal for STI Patterned Wafer

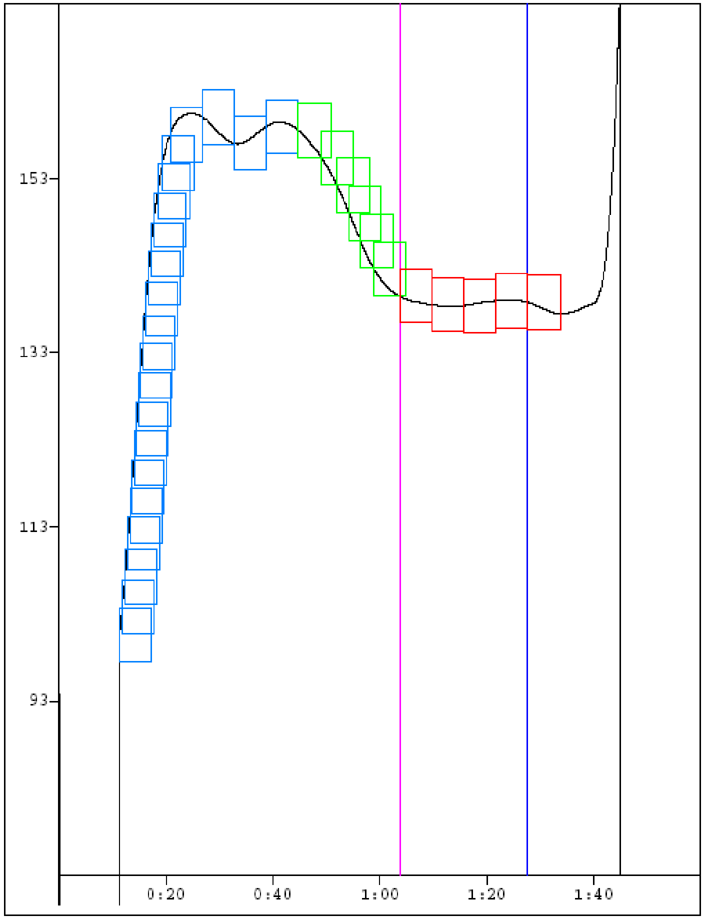
(e.g. wafer set C)



Phase II: Motor Current Endpoint Detection Results

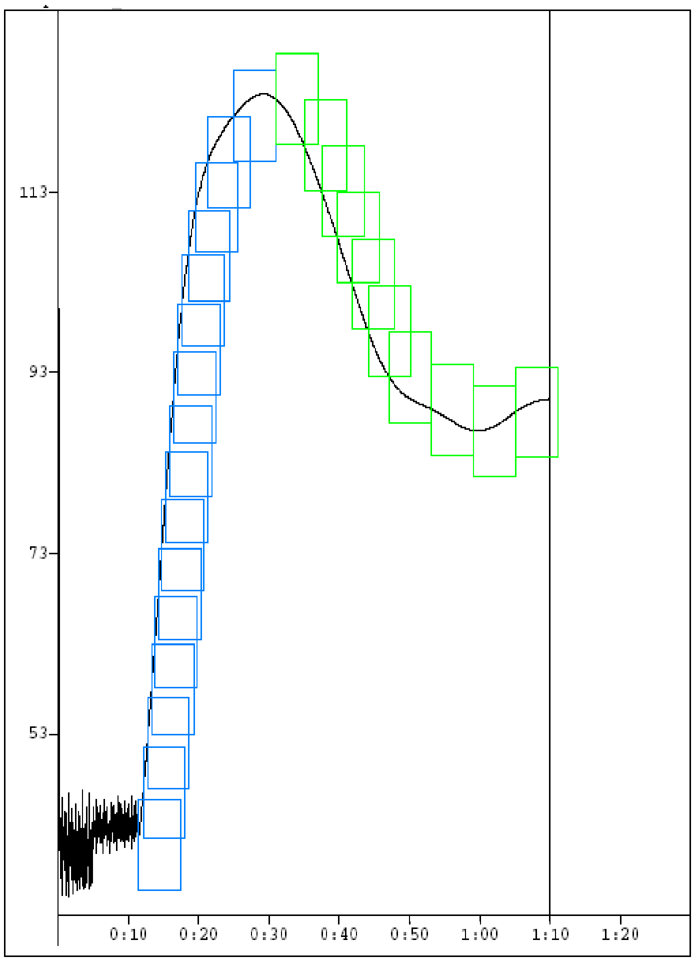


Wafer set A

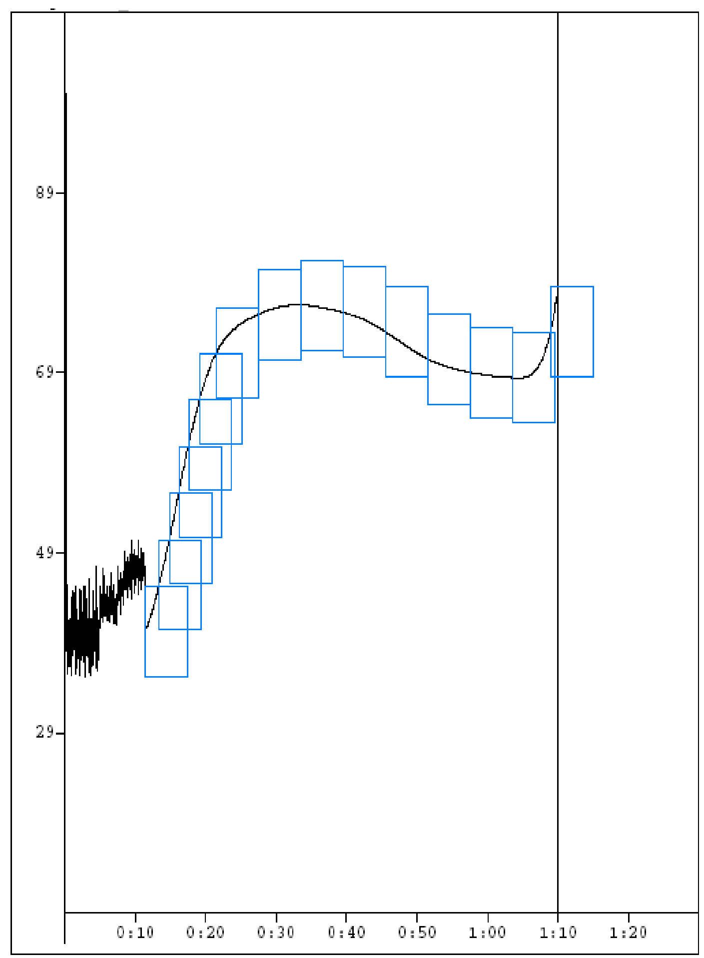


Wafer set B

Phase II: Motor Current Endpoint Detection Results



Wafer set C



Wafer set D

Phase III: Motor Current Endpoint Results

- Based on the film thickness results, wafer sets A through C polished to within oxide thickness specifications
- Wafer set D consistently generated a premature endpoint signal
  - This is suspected to be a result of the high oxide pattern density variation

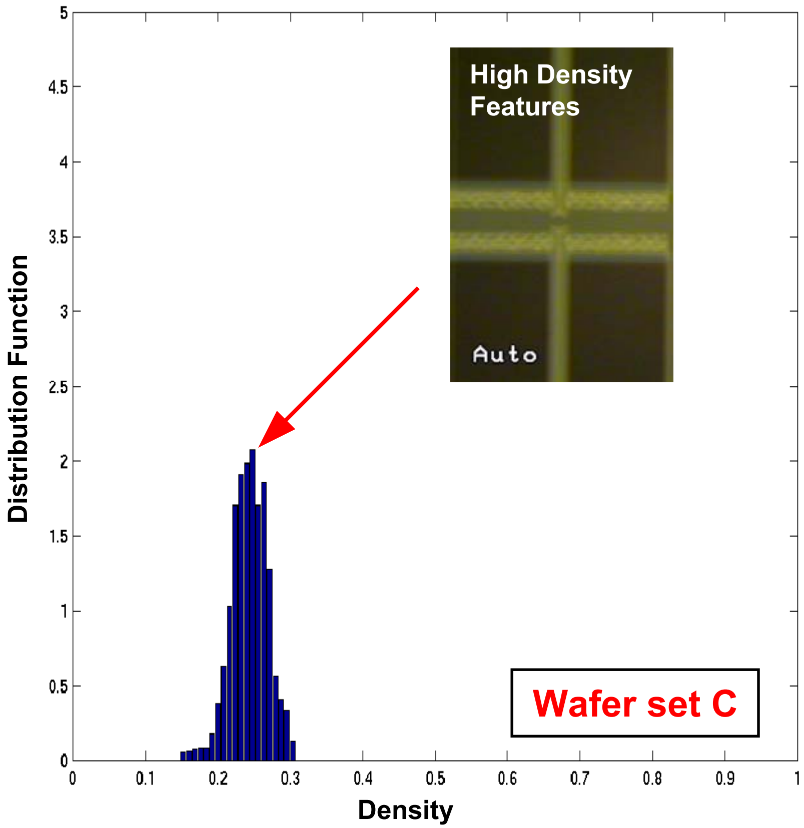
Wafer Set	Average Polish Time (sec)	Final Nitride Thickness (Å)	Final Trench Oxide Thickness (Å)	Oxide Spec (Å)
A	100	1846.99	5908.53	6000 ± 250
B	109	1925.65	6068.91	
C	87	987.56	3560.41	3500 ± 250
D	78	1096.53	3932.04	

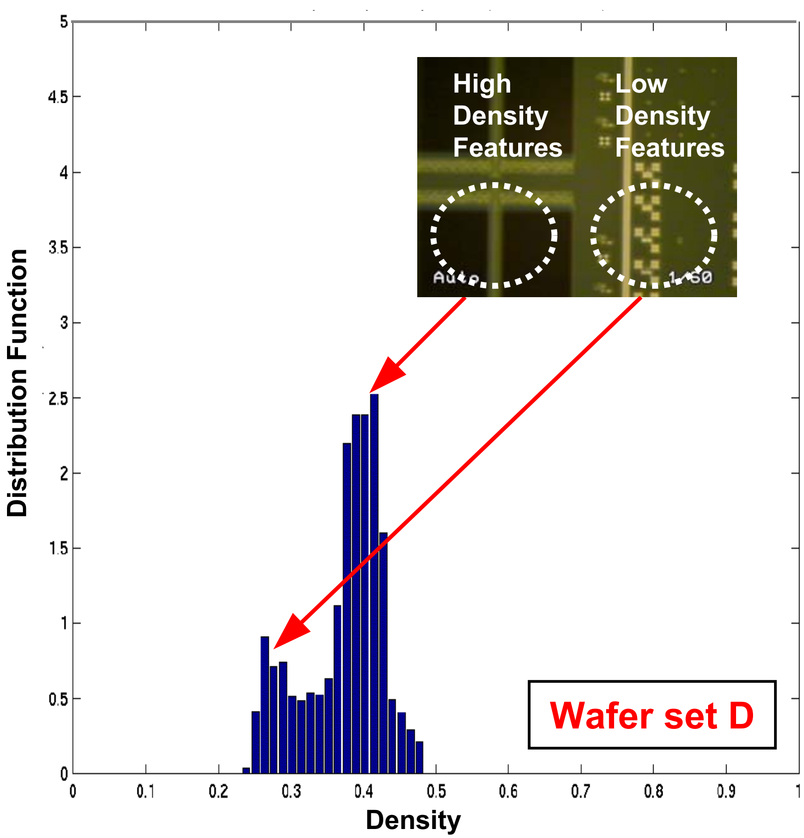
- Results indicate that motor current endpoint detection is a feasible and reliable method for controlling STI CMP processes with certain oxide pattern density limits

Reasons for Endpoint Failure

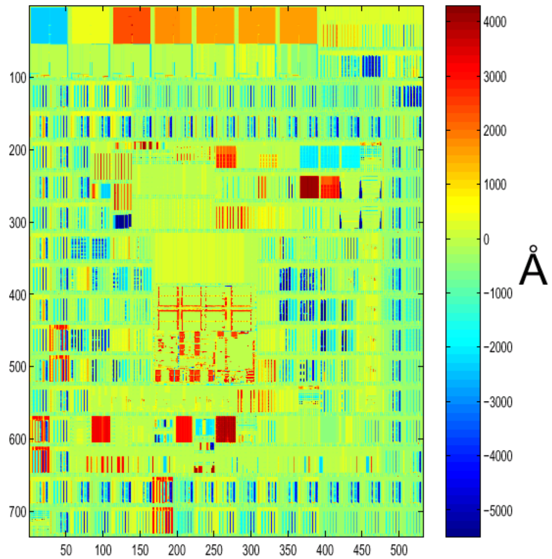
Wafer Set	Oxide (%)				Nitride (%)		Final Trench Oxide Thickness
	Density Variation	Max	Min	Mean	Density Variation	Mean	
C	15.9	30.7	14.8	24.3	59.1	41.3	3560.41
D	25.2	48.4	23.2	37.3	62.2	41.4	3932.04

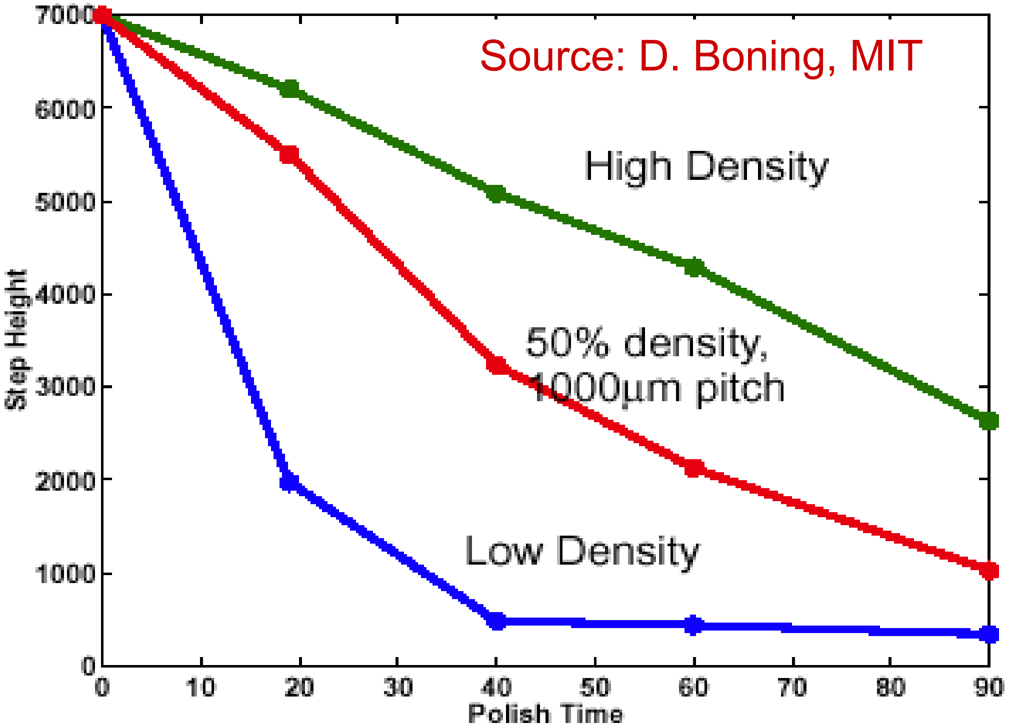
Comparing sets C and D…only variable is the oxide pattern density variation

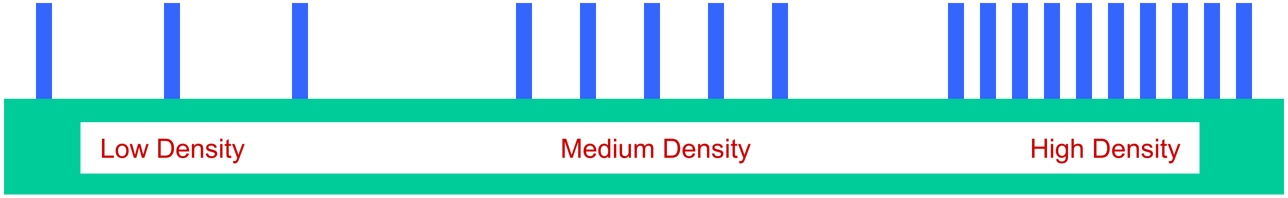




Impacts of Oxide Density Variation on CMP

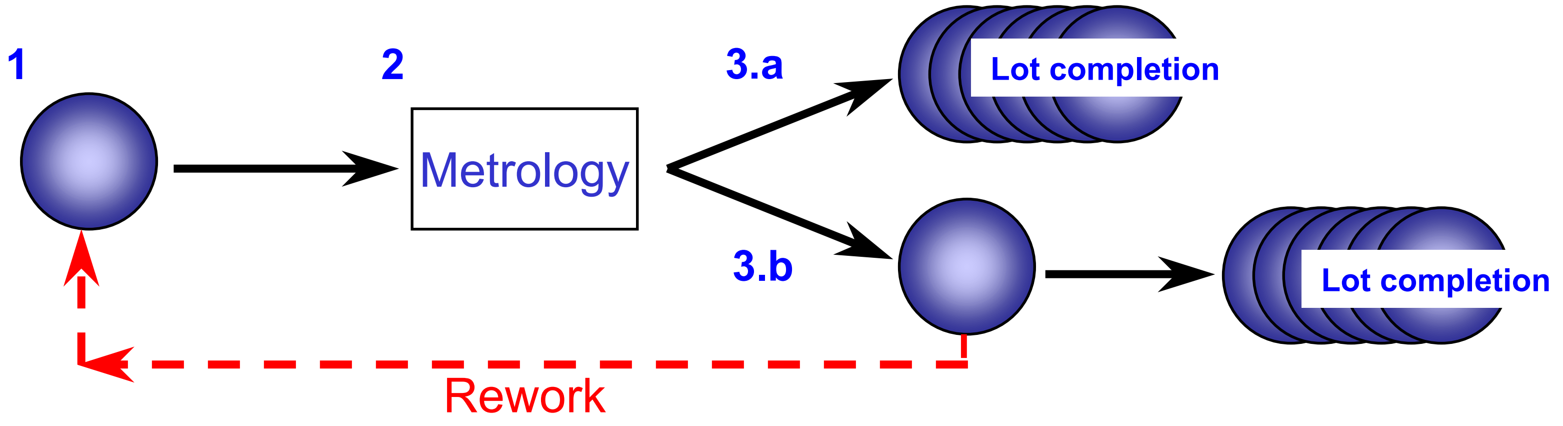






Impact of Endpoint Detection on CMP Reworks

- *Rework* – Remedial processing steps that must follow an initial faulty CMP polish to ensure module target specifications are met
- Rework times and conditions vary depending on the extent of remaining material on the wafer needed to be removed
- It is estimated that reworks are performed on ~10 percent of all wafers in production
- Typical CMP processing involves several steps for adequate planarization
  1. An initial polish with a proposed process recipe
  2. Film thickness measurement
  3. a. Initial process recipe is adequate and lot can be completed
     b. Rework of initial wafer until adequate planarity is achieved (repeat step 1)



Impacts on Slurry Minimization

- Without endpoint monitoring, typical STI polish could involve a rework in the form of an over-polish:
  - A over-polish can average around 15 seconds and would involve additional slurry usage, pad conditioning and pad wear

Wafer Set	Typical Polish Time Including Potential Rework Time (sec)	Average Slurry Use (cc/min)	Average Endpoint Polish Time (sec)	Average Endpoint Slurry Use (cc/min)	*Percent Reduction Per Polish*
A	111	416.25	99	371.25	*10.8*
B	117	438.75	108	405	*7.7*
C	97	363.75	86	322.5	*11.3*
D	90	337.5	78	292.5	*13.3*

- A comparison between typical polish times and endpoint polish times shows that one could potentially save as much as 15 percent slurry per polish & 12 seconds polish time per polish

Impacts on Cost of Ownership (COO)

- Consider a COO model with the following assumptions:
  (S. Olsen, Master's Thesis, University of Arizona, 2002)

  - 200-mm wafer factory
  - 5000 wafer starts per week (operating 52 weeks per year)
  - 300 polishes per pad
  - 225 cc per minute slurry usage
  - Comparing average process time for STI CMP with and without rework (~ 12 seconds)

Approximately $ 200,000 savings per year when using a motor current endpoint detection system & assuming the elimination of CMP reworks

Conclusions

- Motor current endpoint detection can be achieved on STI patterned wafers under ex-situ polishing conditions
- Oxide pattern density variation has an apparent impact on endpoint detection (i.e. high oxide density variations allow certain regions to polish more quickly, thus causing a premature endpoint signal)
- Utilization of motor current endpoint detection for STI CMP could reduce slurry consumption by as much as 15 percent per polish
- Smart STI designs (i.e. density variation constraints) could lead to more versatile endpoint monitoring applications
  - This would provide significant advantages to manufacturing yield and reduce consumable costs

Future Works

- Transfer motor current endpoint technique to multiple tools for verification and application (SNL)

- Work in conjunction with Duane Boning & Xiaolin Xie (MIT) to model removal rate of patterned wafers used in this study
  - Provide verification of false endpoint signal seen with STI wafers of high oxide pattern density variation
  - Develop limits on oxide pattern density variation for future STI architecture

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