NOVA On-Line CMP Metrology and Its Use for Lot-to-Lot Process Control

Taber H. Smith, Duane S. Boning

*MIT*

Simon J. Fang, Jerry A. Stefani,
Greg B. Shinn, and Stephanie W. Butler

*Texas Instruments*
Goals of the NOVA/CMP Project

- Assess the Quality of the NOVA On-Line Metrology Tool
  - Gauge Study
  - Failure Rate
  - Long-Term Stability

- Implement Basic Run-by-Run Process Control
Gauge Study Performed to Measure ...

- Variability due to measurement.
- Variability due to pattern recognition.
- Variability due to software wafer alignment.
- Variability due to loading.
- Variability due to slurry.
- Variability due to polishing.
Repeatability Summary

• Measurement Repeatability (Precision)
  – Standard Deviation of 0.5 Ang.
  – Precision metric (std/mean) of 0.006%; the spec is 0.1%.

• Pattern Recognition Repeatability
  – Standard Deviation of 4.3 Ang.
  – Precision metric (std/mean) of 0.05%; the spec is 0.2%.

• Software Alignment Repeatability
  – Standard Deviation of 8.1 Ang.
  – Precision metric (std/mean) of 0.09%; the spec is 0.3%.
Gauge Study Performed to Measure ...

- Variability due to measurement.  
  - 0.5 Angs.
- Variability due to pattern recognition.  
  - 4.3 Angs.
- Variability due to software wafer alignment.  
  - 8.1 Angs.
- Variability due to loading.  
  - ?
- Variability due to slurry.  
  - ?
- Variability due to polishing.  
  - ?

- Spread at Pre-Polish  
  - 12 Angs.
- Spread due to Cleaning  
  - 8 Angs.
- Spread at Post-Polish  
  - 30 Angs.
- Variability due to loading+slurry+processing  
  - 10 Angs.
NOVA Post-Polish Thickness (Patterned Wafers)

- **Cycle Skips**
- **Site Not Found Errors**
Pre-Clean Nova vs. Post-Clean UV1280
(Region 1, Beginning)

NOVA
83% Success Rate

UV1280
100% Success Rate

~32 Ang. Spread
200 Ang. Offset

65 NOVA Cycle Skips
3 NOVA Site-Not-Found Errors
Pre-Clean Nova vs. Post-Clean UV1280 (Region 2, After Bounds on NOVA Tightened)

NOVA
99% Success Rate

UV1280
100% Success Rate

~31 Ang. Spread
251 Ang. Offset

1 NOVA Cycle Skips
3 NOVA Site-Not-Found Errors
Pre-Clean Nova vs. Post-Clean UV1280 (Region 3, Bounds Re-opened & Algorithm Changed)

~29 Ang. Spread
190 Ang. Offset

NOVA
99.5% Success Rate

UV1280
100% Success Rate

0 NOVA Cycle Skips
1 NOVA Site-Not-Found Errors
Pre-Clean Nova vs. Post-Clean UV1280 (Polished Patterned Wafers Overall)

- NOVA: 93% Success Rate
- UV1280: 100% Success Rate

- 212 Ang. Offset
- ~30 Ang. Spread

- 66 NOVA Cycle Skips
- 7 NOVA Site-Not-Found Errors
Goals of the NOVA/CMP Project

- Assess the Quality of the NOVA On-Line Metrology Tool
  - Gauge Study
  - Failure Rate
  - Long-Term Stability

- Implement Basic Run-by-Run Process Control
Run by Run Control Experiment Plan

**Blanket Pilot Wafer**
- Used to monitor particles, uniformity, and to calculate the blanket wafer-level polish rate to verify MIT model.

**Patterned Wafer**
- NOVA meas. used to calculate EWMA and new polish time.

**MIT Patterned Wafer**
- Measured ex-situ.
- Used to study the planarization length over the life of a CMP pad.
Reliability Testing Summary

• 99% wafer alignment success rate
  – 1 failure in 96 wafer loads.

• 99.7% site measurement success rate
  – 7 site not found errors in 2112 measurements.

• NOVA System froze 2 times in 600 wafers over three days
  – tries to keep measuring after wafer unloads,
  – reboot takes less than 5 minutes.

• NOVA Wafer Handler Controller failed 1 time
  – restart takes about 30 seconds.
Offset Between NOVA and UV1280

• Offset = Average of (NOVA - UV1280)
• Offset at Pre-Polish
• Offset from Cleaning
• Offset at Post-Polish
• Unknown Effects
  – Higher cleaning due to surface damage is known (Discussion with Greg Hames)
  – This number seems consistent with these results
  – Need to verify this measuring pre- and post- on NOVA
  – Determine if this offset is a function of the device

  ▪ 47 Angs.
  ▪ -137 Angs.
  ▪ -212 Angs.
  ➔ -100 Angs.
EWMA Rate Estimation

- Calculate an Exponentially Weighted Moving Average (EWMA) of previously measured rates

\[ Rate_{EWMA}[n] = w \cdot Rate_{Measured}[n] + (1 - w) \cdot Rate_{EWMA}[n - 1] \]

- The higher \( w \), the more recent values are weighted.
- The weight is chosen based on how noisy the process is.
**EWMA Rate Estimation**

Estimate the rate to determine the process time.

See T. Smith and J. Stefani TAR on Control of Metal Sputter Deposition
Controlled Average Thickness (Polished Patterned Wafers)

Lot #

Controlled Average Thickness (Polished Patterned Wafers)

MSE = 120 Ang.

Lot Break-in

MSE = 96 Ang.

After Nova Tweaked

MSE = 280 Ang.

Lot #
Uncontrolled Average Thickness (Polished Patterned Wafers)

- 2 Lot Break-in
- After Nova Tweaked
- MSE = 315 Ang.
- MSE = 315 Ang.
- MSE = 327 Ang.
Uncontrolled Average Thickness (Polished Patterned Wafers)

Lot #

MSE = 241 Ang.
MSE = 256 Ang.
MSE = 280 Ang.

4 Lot Break-in
After Nova Tweaked
Controlled Average Thickness
(5 Sites on Polished Patterned Wafers)

![Graph showing average thickness across different lots for three regions. The graph includes average MSE values for each region: MSE = 308 Ang., MSE = 280 Ang., MSE = 130 Ang.](image)
Using Pilot Wafers with SFE to Control Average Patterned Wafer Thickness

![Graph showing thickness measurements over different lots.](image)

- **4 Lot Break-in**
- **After Nova Tweaked**
- **MSE = 125 Ang.**
- **MSE = 139 Ang.**
- **MSE = 238 Ang.**
**CMP Without NOVA and RbR Control**

10 Minutes
Polish Look-Ahead and Pilot Wafers

30 Minutes
Clean

5 Minutes
Measure

Calculate Polish Time

Polish Lot
90 Minutes

Clean
30 Minutes

Measure
10 Minutes
(2 Wafers)

Total Time (Best Case): 2 Hours 55 Minutes
CMP *With* NOVA and RbR Control

12 Minutes

- Polish Look-Ahead and Pilot Wafers
- NOVA Measure
- Calculate Polish Time

90 Minutes

- Polish Lot
- NOVA Measure

30 Minutes

Clean

Total Time (Simplest Case): 2 Hours 6 Minutes

25% Improvement
CMP *Without* NOVA and RbR Control

10 Minutes
Polish Look-Ahead and Pilot Wafers

30 Minutes
Clean

5 Minutes
Measure

10 Minutes

Polish Lot

90 Minutes

Calculate Polish Time

Polish Lot Clean

Measure

10 Minutes

Calculate Polish Time

Rework Lot 2/24 Wafers

10/45 Minutes

Calculate Polish Time

Rework Lot Clean

Measure

10 Minutes

Total Time (2 Wafer Rework): 3 Hours 45 Minutes
Total Time (24 Wafer Rework): 4 Hours 20 Minutes
CMP *With* NOVA and RbR Control

- Polish Look-Ahead and Pilot Wafers
- NOVA Measure
- Calculate Polish Time
  - 12 Minutes

- Polish Lot
  - NOVA Measure
  - Calculate Polish Time
  - 90 Minutes

- Rework Lot
  - 2/24 Wafers
  - 10/45 Minutes

- Clean
  - 30 Minutes

Total Time (2 Wafer Rework): 2 Hours 22 Minutes (37%)
Total Time (24 Wafer Rework): 2 Hours 55 Minutes (32%)
Throughput, COO, and Waste Savings

- Throughput increases of up to 37%.
- Water and peroxide savings of up to 66%.
- Reduced Cost Of Ownership (COO) due to throughput of up to 31%.
- Reduced COO for future facilitation of up to 66%
- Reduced COO due to less ex-situ metrology tools.
COO Savings Due to Improved Quality

- Oxide Deposited = Removal + Window
- Better process control means a smaller window
- A smaller window means less deposited oxide
- Less deposition
  - Higher deposition throughput
  - Less chemical usage
  - Less waste from chamber cleans
Current Conclusions

• The precision, repeatability, and reliability of the NOVA are very good.

• Nova and UV1280 correlate within ~30 Ang.

• Simple EWMA control of patterned wafers using the NOVA results in an average thickness error of 96 Angs.

• This control is a 70% improvement of fixed-time polishing, and a 23% improvement over control using blanket pilots and sheet film equivalents.

• 25-37% increase in throughput.

• Reduced Cost Of Ownership
  – Less cleaning, higher throughput, fewer ex-situ metrology tools, and improved process control