Dimensional Inline Metrology
with the Crosstalk Eliminated (XE)
Atomic Force Microscopy

Sang-il Park
CEO and Chairman
Outline

• Introduction
  – Conventional AFM
  – New Generation AFM with Flat Scan & True Non-Contact mode

• Optimized AFM Solutions for Slider Metrology
  – PTR, PDD (Programmable Data Density)

• Optimized AFM Solutions for Media & Substrate Metrology
  – Automatic Defect Review

• Optimized AFM Solutions for Undercut and Sidewall Metrology
  – Non-destructive CD and Sidewall Measurement of Soft Photoresist
Atomic Force Microscope (AFM)

The Nanotechnology Solutions Partner

Laser

PSPD

Feedback Control

Display

Topography

X-Y Scan Control

Sample

Mirror

cantilever

x-y-z piezo tube scanner

x y -x

Z

Park Systems

www.parkAFM.com
Two Major Problems in Conventional AFM

1. Piezo tube is not an orthogonal 3-D actuator
2. Non-Contact Mode not possible due to slow z-servo response

Even after software flattening, flat surface does not “look” flat.
AFM Technology Innovation

Tube Scanner  Flexure Scanner
New AFM Platform

- Fast z-servo → True Non-Contact AFM
- Flat x-y scan → Precision Nanometrology

Flexure Guided High Force Z-Scanner

Parallel Kinematic 2D Flexure Scanner
Flat XY Scan: Precision Metrology

Z Run-out (full scan)

Maximum peak-to-peak = 0.871 nm
Repeatability = 0.481 nm
Highly Linear & Orthogonal Scan

2D 100nm Standard (5x5um scan)
4,096x4,096 pixel image
Faster Z-servo Enables True NC-AFM

- Small amplitude
- Minimized tip-sample interaction
- Less sample damage
- Longer tip life
New Generation AFM:

- Accurate imaging of shallow sample features
  - Low residual bow and removal of tapping artifacts
- Better repeatability & reproducibility
  - Results less dependent on location and tips
- Better system to system matching
  - Fewer metrology artifacts in data
- Longer tip life
  - Less tip wear and tear
Pole tip recession (PTR)

- If average PTR is 0.5nm too high, electrical performance yields drop by 10%, and if 0.5nm too low, 5% of hard drives could crash.
- PTR Tolerance for future heads may drop further.
- This requires PTR Gauge Sigma of less than 0.1nm!
SS2 and SF region is much softer than ABS and OC region!
True Non-Contact AFM

<table>
<thead>
<tr>
<th>OC</th>
<th>SS2</th>
<th>SF</th>
</tr>
</thead>
<tbody>
<tr>
<td>-12.25</td>
<td>-0.77</td>
<td>-1.53</td>
</tr>
</tbody>
</table>
### Tapping Mode, 15%

<table>
<thead>
<tr>
<th>OC</th>
<th>SS2</th>
<th>SF</th>
</tr>
</thead>
<tbody>
<tr>
<td>-12.51</td>
<td>-0.95</td>
<td>-1.72</td>
</tr>
</tbody>
</table>

![Graphs showing measurements in nm and µm for OC, SS2, and SF modes.](image)
**Tapping Mode, 30%**

<table>
<thead>
<tr>
<th>OC</th>
<th>SS2</th>
<th>SF</th>
</tr>
</thead>
<tbody>
<tr>
<td>-13.11</td>
<td>-1.19</td>
<td>-1.89</td>
</tr>
</tbody>
</table>
Programmable Data Density

- Automatically detects the region of interest
- Takes a higher pixel density image for the region

- Region of Interest (Writer Pole)
- Not enough pixels in normal PTR image
1-D PDD (Programmable Data Density)

More Y-axis pixels per µm

Normal Scan

PDD Scan

2-D PDD (more pixels for both X and Y-axis) is realized!
2D PDD for Writer Pole

Normal Scan

Y 1026 pixels over 40 µm
Hence 25.6 pixels per µm

X 256 pixels per 20 µm
Hence 12.8 pixels per µm

PDD Scan

Y 512 pixels over 5 µm
Hence 102.4 pixels per µm

X 128 pixels per 4 µm
Hence 32 pixels per µm
2D PDD for Writer Pole

Normal Scan

PDD Region

Y-pixels

Writer Pole is visible

X-pixels

PDD Scan

Y
1026 pixels over 40 µm
Hence 25.6 pixels per µm

Y
512 pixels over 5 µm
Hence 102.4 pixels per µm

X 256 pixels per 20 µm
Hence 12.8 pixels per µm

128 pixels per 4 µm
Hence 32 pixels per µm

Confidential and Proprietary
PTR Gage for 72 Sliders

Gage R&R

<table>
<thead>
<tr>
<th>Source</th>
<th>VarComp (of VarComp)</th>
<th>%Contribution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Gage R&amp;R</td>
<td>0.004079</td>
<td>0.90</td>
</tr>
<tr>
<td>Repeatability</td>
<td>0.004079</td>
<td>0.90</td>
</tr>
<tr>
<td>Part-To-Part</td>
<td>0.449862</td>
<td>99.10</td>
</tr>
<tr>
<td>Total Variation</td>
<td>0.453941</td>
<td>100.00</td>
</tr>
</tbody>
</table>

Number of Distinct Categories = 14

Gage R&R for PTR c

<table>
<thead>
<tr>
<th>Group</th>
<th>Average (nm)</th>
<th>Stdev (nm)</th>
<th>Repeatability (Å)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>-0.535</td>
<td>0.668</td>
<td></td>
</tr>
<tr>
<td>B</td>
<td>-0.497</td>
<td>0.671</td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>-0.547</td>
<td>0.681</td>
<td>0.64</td>
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</tbody>
</table>

Confidential and Proprietary
Gage Study for Writer Pole Height

Gage R&R

<table>
<thead>
<tr>
<th>Source</th>
<th>%Contribution</th>
<th>%Study Var</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Gage R&amp;R</td>
<td>0.004026</td>
<td>13.83</td>
</tr>
<tr>
<td>Repeatability</td>
<td>0.004026</td>
<td>13.83</td>
</tr>
<tr>
<td>Part-To-Part</td>
<td>0.206505</td>
<td>99.04</td>
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<tr>
<td>Total Variation</td>
<td>0.210531</td>
<td>100.00</td>
</tr>
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</table>

Number of Distinct Categories = 10

Gage R&R for PWP

<table>
<thead>
<tr>
<th>Group</th>
<th>Average (nm)</th>
<th>Stdev (nm)</th>
<th>Repeatability (Å)</th>
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</thead>
<tbody>
<tr>
<td>A</td>
<td>1.220</td>
<td>0.471</td>
<td></td>
</tr>
<tr>
<td>B</td>
<td>1.235</td>
<td>0.463</td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>1.220</td>
<td>0.442</td>
<td>0.635</td>
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</table>
Key Benefits of Programmable Data Density

• One Scan (~5 minutes) obtains
  – Normal PTR image
  – Writer Pole image with high pixel density
  – For conventional AFM, it takes ~30 minutes or longer

• Multiple PDD zones are possible
Optimized AFM Solution
for Media & Substrate Metrology
- Candela or Tester locates and mark defects.
- The smaller defects can be imaged in detail ONLY by an AFM.
Current Method of Defect Inspection

- Defect Marking by Optical Microscope
  - Throughput: less than 5 defects/hr

- Manual AFM imaging
  - Throughput: 1~2 defects/hr

- Defect Mapping by Candela
  - Throughput: 10 defects/day at best

- Low Throughput: 10 defects/day at best
- High Tip Cost: destructive scan method (Tapping mode)
Defect Map Transfer to AFM

Candela or Tester

<table>
<thead>
<tr>
<th>Defect</th>
<th>$d_1$</th>
<th>$d_2$</th>
<th>$d_3$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$x$</td>
<td>$x_1$</td>
<td>$x_2$</td>
<td>$x_3$</td>
</tr>
<tr>
<td>$y$</td>
<td>$y_1$</td>
<td>$y_2$</td>
<td>$y_3$</td>
</tr>
</tbody>
</table>

AFM: automatic search and scan

<table>
<thead>
<tr>
<th>Defect</th>
<th>$d_1$</th>
<th>$d_2$</th>
<th>$d_3$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\theta$</td>
<td>$\theta_1$</td>
<td>$\theta_2$</td>
<td>$\theta_3$</td>
</tr>
<tr>
<td>$r$</td>
<td>$r_1$</td>
<td>$r_2$</td>
<td>$r_3$</td>
</tr>
</tbody>
</table>
Challenges in Developing Automatic Defect Review AFM

Defect signal is tiny in Survey Scan
- Small defects imaged in one or two pixels.
- Signal level often low

We need AFM with,
- Low system noise, less than 0.5A rms
- Artifact-free AFM scan
- Non-destructive scan mode
Key Benefits of Automatic Defect Review AFM

1. Over 500 ~ 800% gain in throughput
2. 20 times longer tip life, saving over $500,000 in tip cost for 3~5 year run
3. Automation allows users to manage multiple AFMs simultaneously
Optimized AFM Solution for Undercut & Sidewall Metrology
In PMR head manufacturing, photoresist elements with overhang shape & their negative trenches need to be characterized.

Need to measure the sidewall angle and critical dimension (CD).
• Data acquisition at three tilt angles of $0^\circ$, $40^\circ$, $-40^\circ$. 
3D AFM: Metal Overhang Structure
Interference pattern of standing wave
Photoresist (PR) Line After Tip Deconvolution

<table>
<thead>
<tr>
<th>Measurement Sample</th>
<th>System</th>
<th>Source</th>
<th>Top Width</th>
<th>Middle Width</th>
<th>Bottom Width</th>
<th>Height</th>
<th>Measurement Date</th>
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</thead>
<tbody>
<tr>
<td>Wafer#2</td>
<td>Tool#2</td>
<td>Repeatability</td>
<td>0.38</td>
<td>0.37</td>
<td>0.33</td>
<td>0.23</td>
<td>2009-08-28</td>
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<tr>
<td></td>
<td></td>
<td>Site Variation</td>
<td>1.75</td>
<td>2.05</td>
<td>2.77</td>
<td>2.58</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Total Variation</td>
<td>1.78</td>
<td>2.09</td>
<td>2.79</td>
<td>2.59</td>
<td></td>
</tr>
</tbody>
</table>
Key Benefits of New 3D AFM

- Undercut or Sidewall Imaging
- Sidewall Roughness Measurement
- Imaging of Soft Photoresist Structures

Hence, complete 3D metrology of

- critical dimensions
- critical angles
- sidewall roughness
Conclusion

• AFM has evolved from a qualitative imaging tool to a quantitative nano-metrology tool for industry

• Automated AFM solution for inline slider metrology was developed

• True Non-Contact mode is a critical requirement for accurate PTR measurement

• Programmable data density is a throughput efficient solution for production scalable AFM metrology

• Automated AFM solution for automatic defect review was developed

• New Generation 3D AFM was developed for inline 3D measurement of undercut and sidewall metrology