Traceable Pitch Metrology: Supporting the Development of Patterned Media and More

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Outline

- Review accuracy requirements
- **Measure pitch** of a new 70-nm grating.
- Make it **traceable** to the SI meter, including uncertainty of mean pitch and single pitch values. (Joint project with NIST (USA) and NMC (Singapore))
- Define a **calibration roadmap to 5-nm pitch** standards.
- Height measurements with 1 Picometer precision
- **Line Edge Roughness**
## Length Metrology Requirements

### Hint: 25 nm pitch 2-Dimensional array = 1 Tb/in²

<table>
<thead>
<tr>
<th>Device Feature</th>
<th>Size</th>
<th>Tolerance (3σ)</th>
<th>Gauge Uncertainty (3σ)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Optical Disk track pitch</td>
<td>&gt; 100 nm</td>
<td>3-4%</td>
<td>1%</td>
</tr>
<tr>
<td>Magnetic Disk track pitch</td>
<td>50 nm and shrinking</td>
<td>10-20%</td>
<td>3%</td>
</tr>
<tr>
<td>Semiconductor Gate CD</td>
<td>25 nm and shrinking</td>
<td>10.30%</td>
<td>2%</td>
</tr>
</tbody>
</table>

### Goal for Traceable Standards

<table>
<thead>
<tr>
<th></th>
<th>Expanded uncertainty (k=2, 95% confidence)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>0.50%</td>
</tr>
<tr>
<td>Single Values</td>
<td>1.33%</td>
</tr>
</tbody>
</table>

Pole tip width, length and recession also demand high precision and accuracy.
Methods - Traceability Path

- Goal: “Traceable to SI meter” (“NIST-traceable” is old-fashioned expression)
- PTB optical diffraction lab – mean pitch of 144 nm grating
- At ASM: use 144 nm grating as Transfer Standard
- Calibrated Length Scale of AFM
- Calibrated Measurements of 70 nm test specimen.
- Report uncertainty both for mean and single values of pitch
Materials: Test Specimen and Transfer Standard

70-1DUTC: 70 nm Pitch, SiO2 on Si, height 35 nm
150-2DUTC: 144 nm Pitch, Al on Si, height 88 nm, column average height 52 nm
AFM Data Capture

- open-loop AFM: NanoScope® IIIA, Dimension 3100 (Veeco/DI).
- Scan size: 3 µm, 512x512 pixels
  - Contact mode: Scan rate 5 Hz;
  - TappingMode™: Scan rate 1.5 Hz
Interleaved Scanning

- Alternate images are on the calibration standard and the test specimen.
  - numbered dots indicate sequence and location of images
Interleaved Calibration

- Each Test image is bracketed by two images of the Standard

- Data Analysis with DiscTrack Plus™
What Calibration Does

Image distortion affects calibration and test measurements in the same way.

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Calibrated pitch is 7x more precise than raw pitch.

Data exclusion zone
Pitch Results for 2 runs, 4 months apart

There was no significant variation in mean pitch from spot to spot.

Run | Count | Mean Pitch (nm) | SD | SD of Mean (estimate 1) | SD of Mean (estimate 2)
--- | --- | --- | --- | --- | ---
1 (Contact Mode) | 375 | 70.071 | 0.202 | 0.0110 | 0.0104
2 (Tapping Mode) | 371 | 70.090 | 0.147 | 0.0062 | 0.0076

1 SD of 11 mean values, 1 for each spot
2 SD of single pitch values / SQRT(Count)
Comparison of ASM with NIST and NMC

- ASM used commercial AFM with transfer standard.
- NIST and NMC used special calibrated AFMs
  - measurements directly traceable to SI meter using interferometers.

<table>
<thead>
<tr>
<th>Run</th>
<th>Mean Pitch (nm)</th>
<th>Expanded Uncertainty (nm) (k = 2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ASM#1</td>
<td>70.071</td>
<td>0.024</td>
</tr>
<tr>
<td>NMC</td>
<td>70.072</td>
<td>0.028</td>
</tr>
<tr>
<td>NIST</td>
<td>70.055</td>
<td>0.027</td>
</tr>
<tr>
<td>ASM#2</td>
<td>70.090</td>
<td>0.021</td>
</tr>
<tr>
<td>ASM combined</td>
<td>70.080</td>
<td>0.016</td>
</tr>
</tbody>
</table>
Roadmap for Traceable Pitch Standards: 300 to 5 nm

<table>
<thead>
<tr>
<th>Pitch (nm)</th>
<th>On Market 2009</th>
</tr>
</thead>
<tbody>
<tr>
<td>292</td>
<td>Y</td>
</tr>
<tr>
<td>144</td>
<td>Y</td>
</tr>
<tr>
<td>70</td>
<td>Y</td>
</tr>
<tr>
<td>35</td>
<td>lab demo only</td>
</tr>
<tr>
<td>20</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td></td>
</tr>
</tbody>
</table>
Roadmap Assumption: Precision < 0.5% ($1\sigma$) will be possible.

So far, so good.
Traceability Chain: Actual and Modeled uncertainties

![Relative Pitch Uncertainty (1 σ)](image)

<table>
<thead>
<tr>
<th>Predicted Expanded uncertainty at 5 nm</th>
<th></th>
</tr>
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<tbody>
<tr>
<td>Mean</td>
<td>0.016 nm (0.32%)</td>
</tr>
<tr>
<td>Single Values</td>
<td>0.052 nm (1.04%)</td>
</tr>
<tr>
<td>1 nm = 1000 pm</td>
<td></td>
</tr>
</tbody>
</table>

📍 We seek samples of fine pitch patterns for testing.
Height Calibration – important for PTR...

- A difficult problem below 10 nm
- Existing traceable calibrators have uncertainty of 2-7%
- What if we could do 10-100x better?
A Calibrated Step: 0.100 +-0.001 nm

- Adjustment Range: 0.1 to 50 nm
- Precision: 0.1% or better for step > 1 nm

- We seek development partner and/or “alpha” customers.
Line Edge Roughness and More

Line Edge Roughness (RMS) = 1.02 nm
LER from SEM image (different sample)

- Left and Right Edges:  0.59 nm rms
- Line center: 0.39 nm
- Line width: 0.90 nm
Factors affecting LER Results

- We examined a single AFM image, processed and analyzed in different ways.
- The following factors are listed in order of decreasing influence on the LER results:
  - **Line Length** – this had a very strong effect on LER (decrease by almost half when the length was decreased by 4x)
  - **Left edge vs. Right Edge** – The right edge roughness was about 8% lower than the left edge roughness
  - **Data Sampling Interval and Averaging** – for constant line length, increasing the section averaging width from 1 line to 8 lines decreased the LER by < 3% and from 1 line to 32 lines, the decrease was < 8%
  - **Image Rotation** – Adjustment of image rotation within ±1 degree resulted in LER variation < 1%
- In other work, we saw that **AFM tip wear** can cause a decrease in LER.
- **Material Variations**
Thanks for your attention

- Please visit booth 125.
- Acknowledgements
  - ASM: David Burkhead
  - NIST: Ron Dixson, Ted Vorburger, George Orji, Joe Fu
  - NMC: Shihua Wang, Siew Leng Tan

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Style guide

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