Nanometers and Picometers: Keys to Success with 5 Terabit/in² Patterned Media

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525 G dot/in² pattern (35 nm pitch, 2D array)

- Measure size, shape and position of the marks

Pitch is the most basic position parameter
Measure Pitch for Consecutive Pairs of Columns

- SEM - Zeiss Supra 55VP
- \( \sigma = 84 \) pm
- Pitch \( \sigma / \text{Mean} = 0.25\% \) (uncorrected, raw data)
### Bump Widths and Lengths

<table>
<thead>
<tr>
<th></th>
<th>Width2 at Middle (nm)</th>
<th>Length2 at Middle (nm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Count</td>
<td>1958</td>
<td>1958</td>
</tr>
<tr>
<td>Mean</td>
<td>20.44</td>
<td>19.68</td>
</tr>
<tr>
<td>Standard Deviation</td>
<td>1.09</td>
<td>0.90</td>
</tr>
<tr>
<td>Standard Error of Mean</td>
<td>0.02</td>
<td>0.02</td>
</tr>
<tr>
<td>Maximum</td>
<td>23.72</td>
<td>22.36</td>
</tr>
<tr>
<td>Minimum</td>
<td>17.14</td>
<td>17.36</td>
</tr>
<tr>
<td>Range</td>
<td>6.58</td>
<td>5.00</td>
</tr>
</tbody>
</table>

![Graph showing Bump Widths and Lengths](image)
# Track Pitch Metrology for Patterned Media

<table>
<thead>
<tr>
<th>Media Type</th>
<th>Magnetic</th>
<th>Optical</th>
</tr>
</thead>
<tbody>
<tr>
<td>Track Pitch (nm)</td>
<td>25-50</td>
<td>100-150</td>
</tr>
<tr>
<td>Removable?</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Track Pitch Variation</td>
<td>3-6%</td>
<td>1-1.5%</td>
</tr>
<tr>
<td>(% of Pitch, 1 ( \sigma ))</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gauge Precision</td>
<td>1-2%</td>
<td>0.33-0.5%</td>
</tr>
<tr>
<td>(% of Pitch, 1 ( \sigma ))</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Example Gauge Test</td>
<td>50 / 0.5-1</td>
<td>150 / 0.75</td>
</tr>
<tr>
<td>(Pitch / 1 ( \sigma ))  (nm)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Picometer Accuracy

- Comparative study with PTB, the German national standards lab.
Materials and Methods—Test Specimens

292 nm Pitch, 1D, Ti on Si  
(Height: 36 nm)

144 nm Pitch, 2D, Al on Si  
(Height: 88 nm,  
column average height 52 nm)
Materials and Methods—Traceability Path

- Physikalisch-Technische Bundesanstalt (PTB) used optical diffraction (OD) to measure the mean pitch of the gratings.
- At Advanced Surface Microscopy (ASM) we used atomic force microscopy (AFM) to measure individual pitch values, which led to mean values and standard deviation.
AFM Data Capture and Analysis

- NanoScope® IIIA, Dimension 3100, open-loop AFM (Veeco Metrology/Digital Instruments).
- We alternated scans of the calibration and test specimen.

- We analyzed height images using Advanced Surface Microscopy’s DiscTrack Plus™ software.
AFM Measurement of Individual Pitch values

Data set has 3 images:
- Calibration Standard
- Test Sample
- Calibration Standard

“Bookend calibration” corrects for short term magnification drift.

292 nm Standard (2 images)

Data exclusion zone

144 nm Grating (1 image)
There was no significant variation in mean pitch from spot to spot.
# Optical Diffraction (OD) Proves AFM Accuracy

<table>
<thead>
<tr>
<th></th>
<th>Optical Diffraction (nm)</th>
<th>AFM Analysis (nm)</th>
<th>Difference (nm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>X direction</td>
<td>143.928</td>
<td>143.895</td>
<td>0.033</td>
</tr>
<tr>
<td>Y direction</td>
<td>143.931</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Uncertainty of</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>mean (1 σ)</td>
<td>0.007 (0.005%)</td>
<td>0.039 (0.027%)</td>
<td></td>
</tr>
<tr>
<td>Uncertainty of</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>single pitch</td>
<td>N/A</td>
<td>0.55 (0.38%)</td>
<td></td>
</tr>
<tr>
<td>values (1 σ)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Optical Diffraction and AFM results agree within the 95% confidence limits, and the difference is mainly due to random error in individual pitch measurements.

Difference in precision could be related to the number of lines measured:
- 7000 in 1 mm spot for OD
- 304 for AFM

$$\sqrt{\frac{7000}{304}} = \text{ca. 5}$$  
Ratio of uncertainties = ca. 5

**33 pm WOW!**
Picometer Precision

- To qualify microscopes and prospective calibration standards:
- Measure pitch in 1 or a few images using self-calibration.
SEM Pitch Measurements of 144 nm Grid - Precision

SEM: Hitachi S4700 at 5 kV.

\( \sigma = 0.43 \text{ nm} \).

Relative \( \sigma = \frac{\sigma}{\text{mean}} = 0.30\% \)

Field Emission SEM and AFM have similar precision for pitch measurements.

<table>
<thead>
<tr>
<th>Pitch (nm)</th>
<th>Count</th>
<th>Mean</th>
<th>Std. Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>143.90</td>
<td>35</td>
<td>143.90</td>
<td>0.43</td>
</tr>
</tbody>
</table>

Pitch Values

Feature Number

Calibration files: 5kV25kxSEMcropped.tif.asm
date files: 5kV25kxSEMcropped.tif.asm
SEM of 76 nm 1-D Grating

- SEM - Zeiss Supra 55VP
- Relative $\sigma = 0.21\%$

The raw pitch results from 9 different images show consistent distortion in the SEM scan.

![SEM image with pitch results chart](chart.png)
Precision of Single Pitch Measurements for Grating Pitch 35-2000 nm

The relative Standard Deviation was in the range 0.22-0.43% for all pitch values from 35 to 2000 nm. At 0.5% relative Standard Deviation for single Pitch values, it is practical to get relative uncertainty of mean < 0.05% in a short data run.
A Chain of Traceable Pitch Calibration Specimens with Mean Accuracy better than 0.1% (10 pm) at 10 nm.

- 144 calibrates 76
  76 → 35
  35 → 20
  20 → 10
  10 → 5 nm

- The uncertainty of mean for “76” depends mainly on the uncertainty of mean of “144”, the uncertainty of single values of “76”, and the number of pitch measurements (N).

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

**Relative Pitch Uncertainty (1 σ)**

- Uncertainty vs. Pitch (nm)
- Single Value
- Mean
- N=300
Summary

◆ Measurement of size and position parameters.
◆ Picometer Accuracy and Precision
  --with “Ordinary” AFMs and SEMs.
◆ Certification of Traceable Calibration Standards
  --A path exists to 10 nm pitch (5 Tb/in²) and beyond.