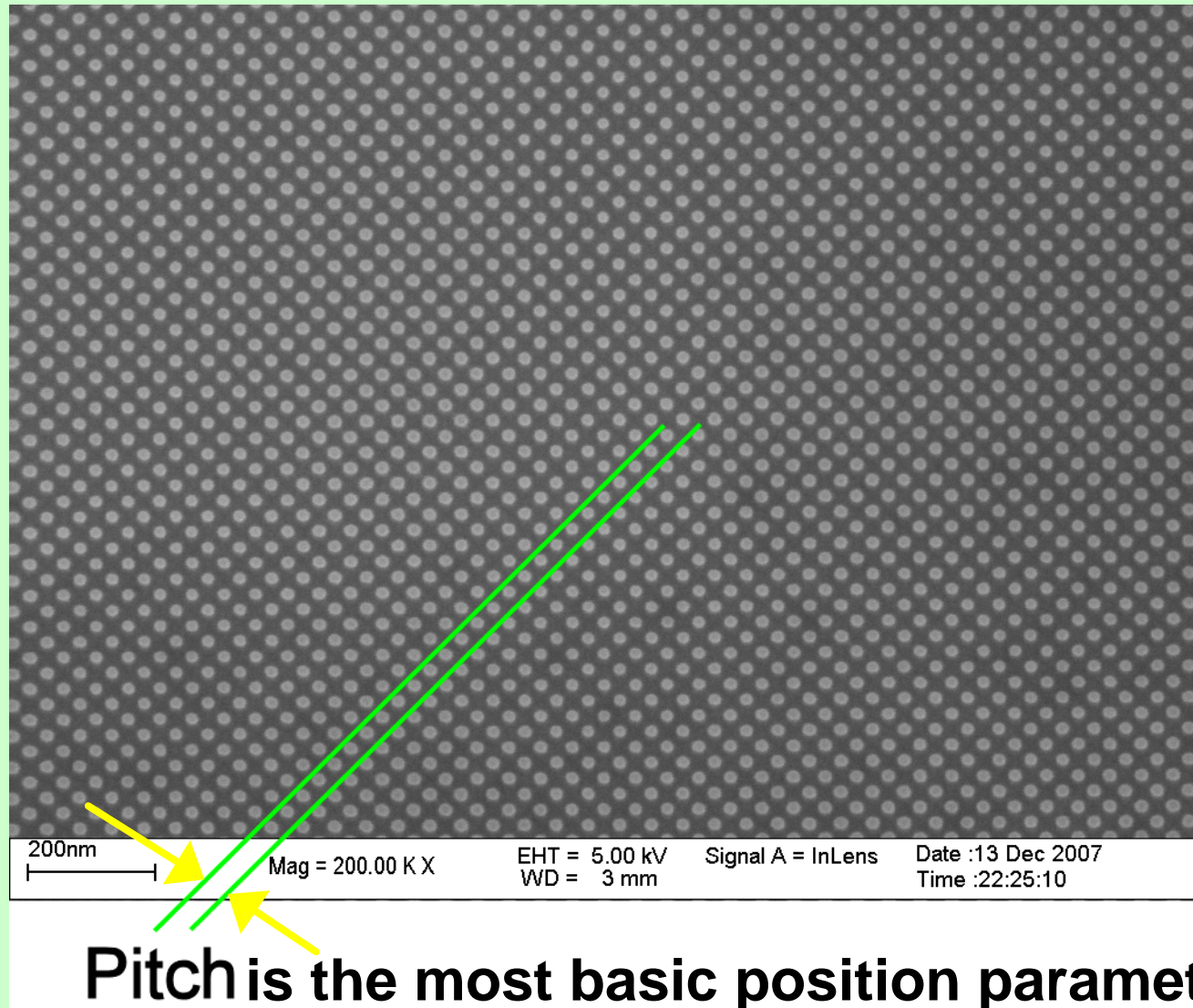


Nanometers and Picometers: Keys to Success with 5 Terabit/in² Patterned Media

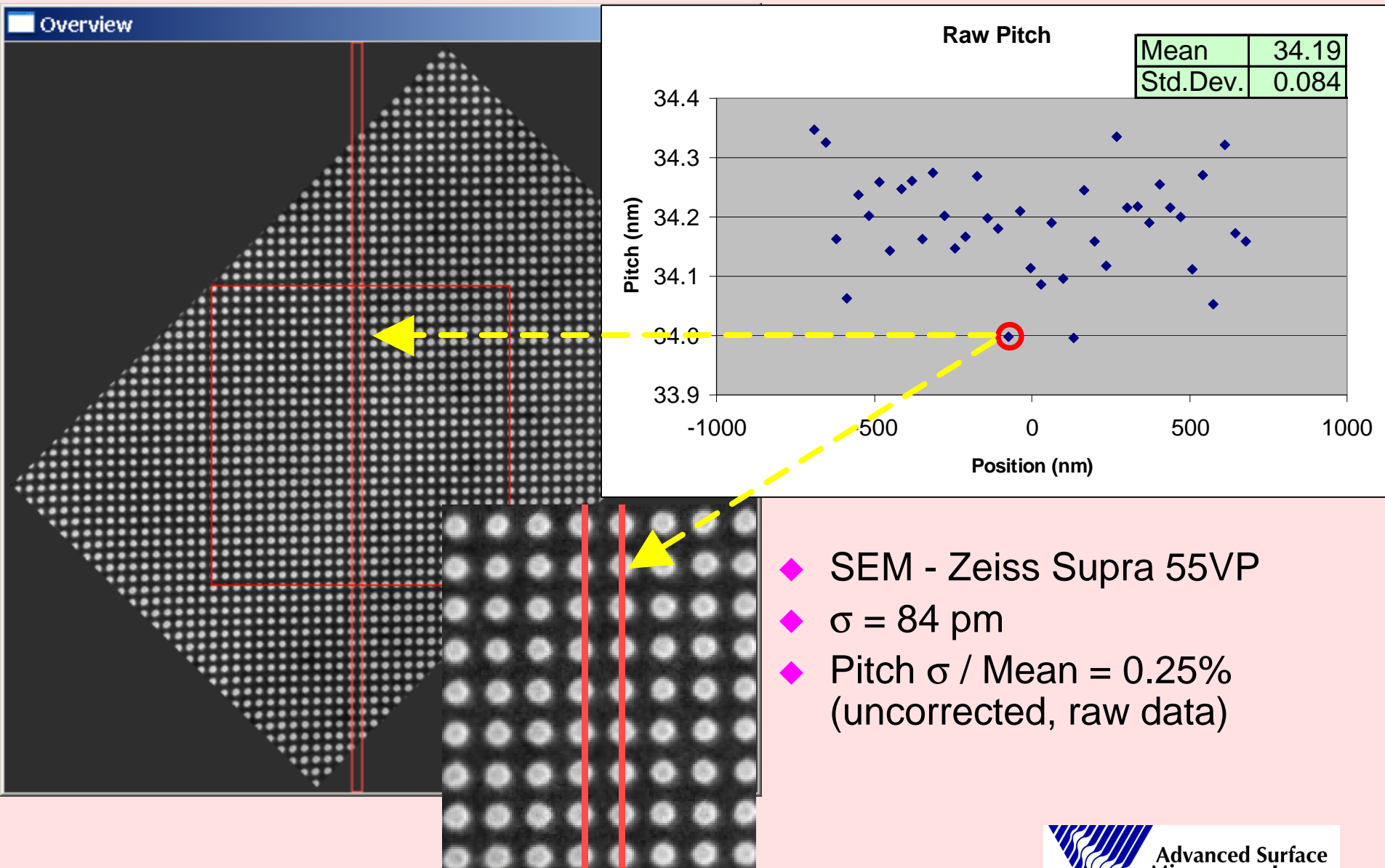
Donald A. Chernoff
Advanced Surface Microscopy Inc.
Indianapolis, IN USA
www.ASMICRO.COM

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

- Measure size, shape and position of the marks

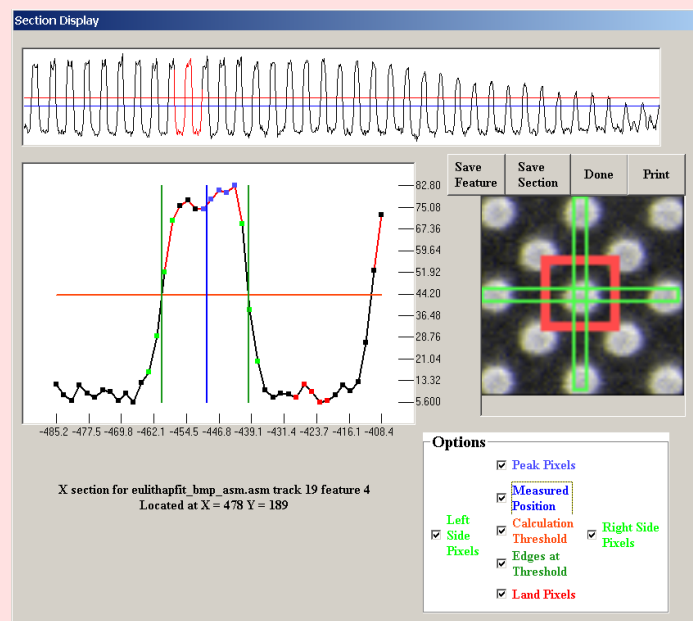
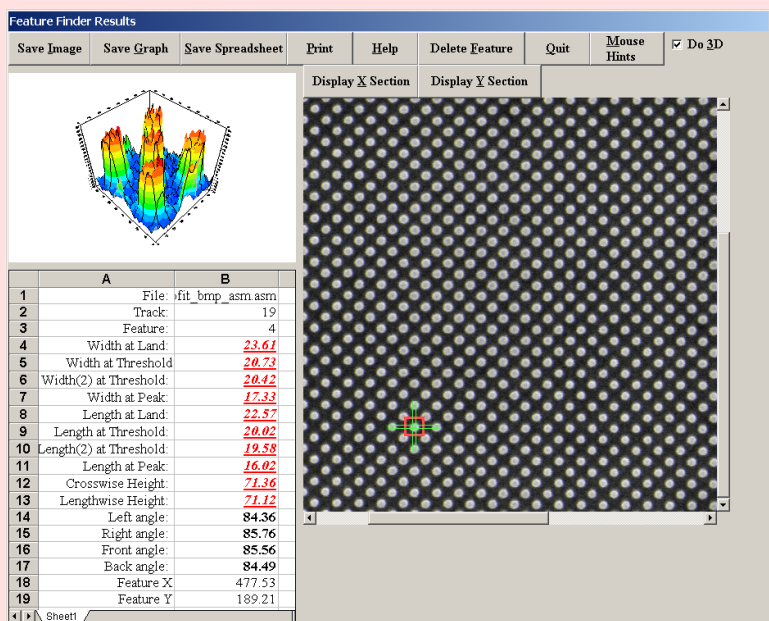
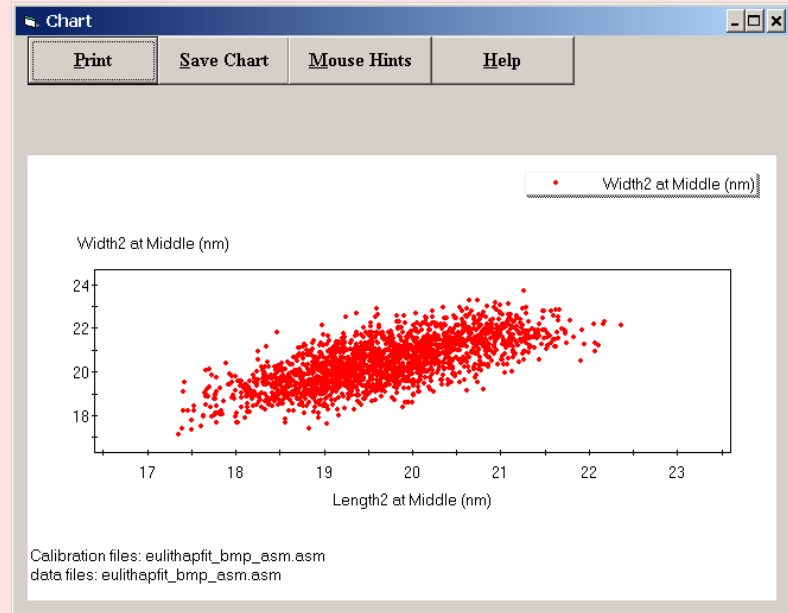


Measure Pitch for Consecutive Pairs of Columns



Bump Widths and Lengths

	Width2 at Middle (nm)	Length2 at Middle (nm)
Count	1958	1958
Mean	20.44	19.68
Standard Deviation	1.09	0.90
Standard Error of Mean	0.02	0.02
Maximum	23.72	22.36
Minimum	17.14	17.36
Range	6.58	5.00



Track Pitch Metrology for Patterned Media

Media Type	Magnetic	Optical
Track Pitch (nm)	25-50	100-150
Removable?	No	Yes
Track Pitch Variation (% of Pitch, 1 σ)	3-6%	1-1.5%
Gauge Precision (% of Pitch, 1 σ)	1-2%	0.33-0.5%
Example Gauge Test (Pitch / 1 σ) (nm)	50 / 0.5-1	150 / 0.75

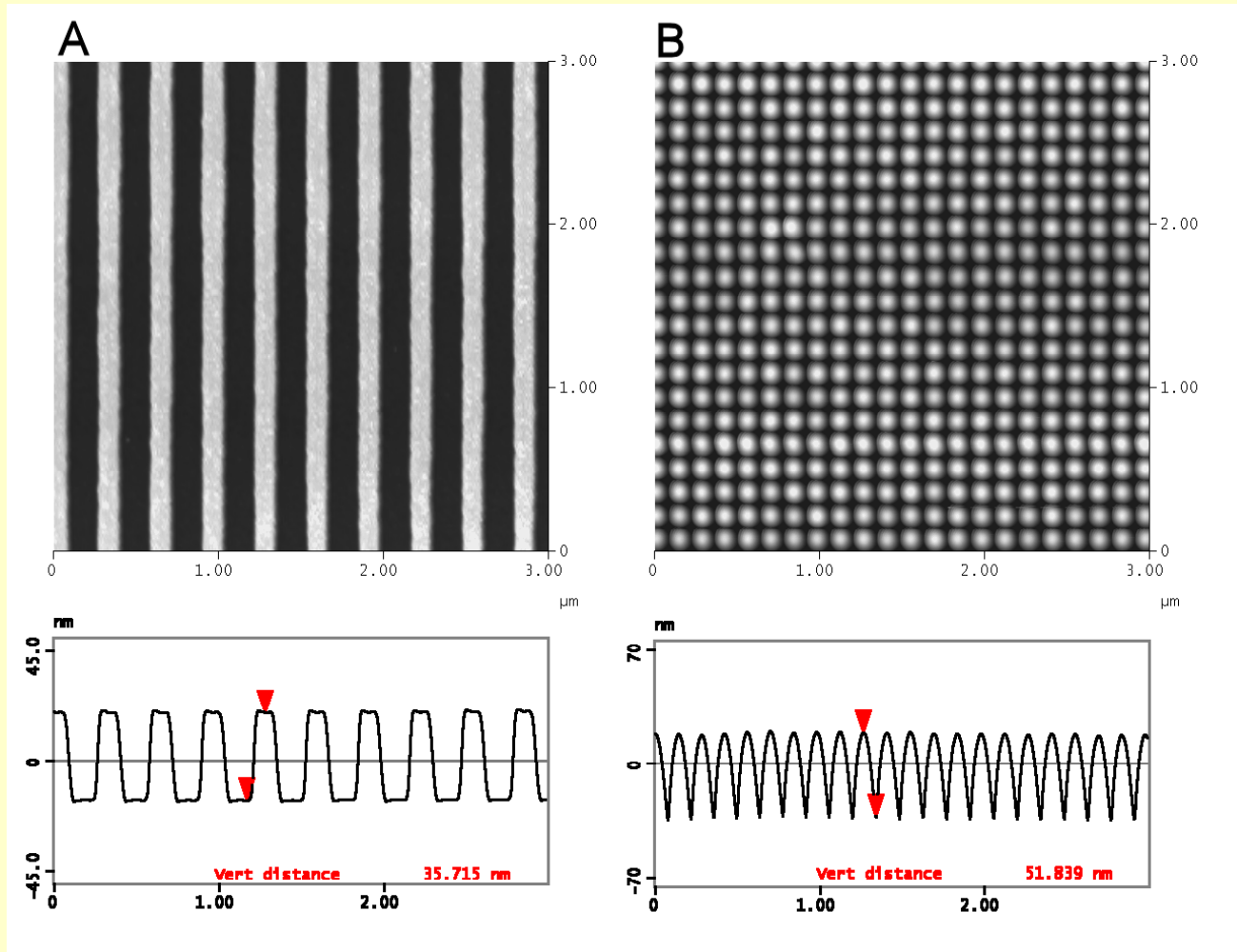
Picometer Accuracy

- ◆ Comparative study with PTB, the German national standards lab.

Materials and Methods—Test Specimens

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

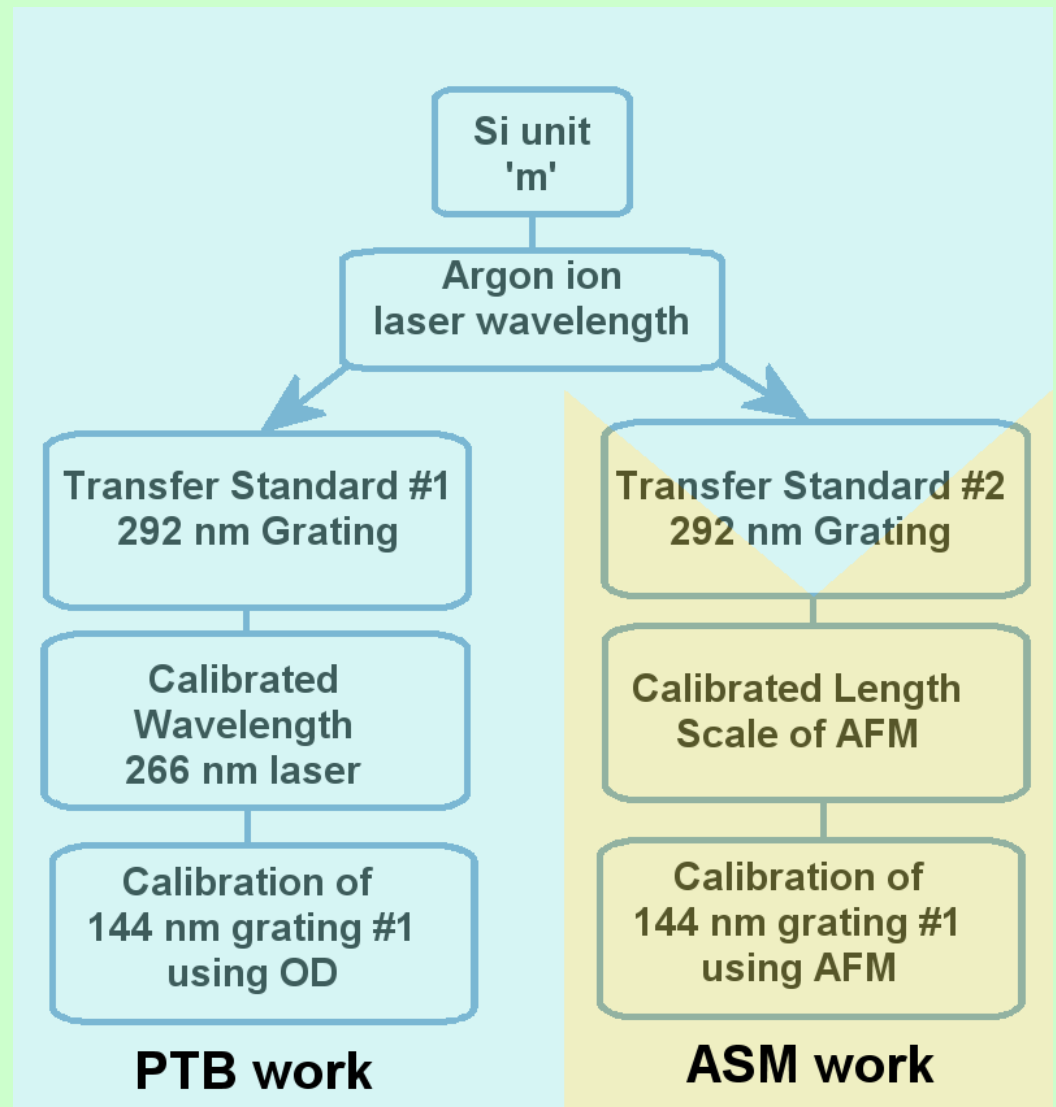
144 nm Pitch, 2D, Al on Si
(Height: 88 nm,
column average height 52 nm)



Materials and Methods—Traceability Path

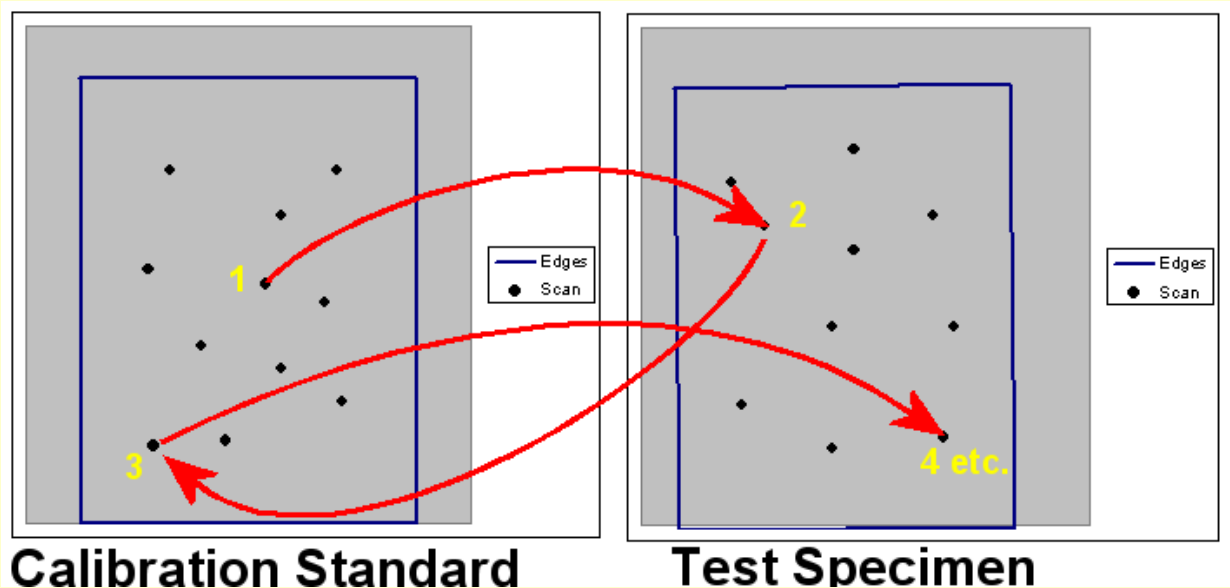
◆Physikalisch-Technische Bundesanstalt (PTB) used optical diffraction (OD) to measure the mean pitch of the gratings.

◆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

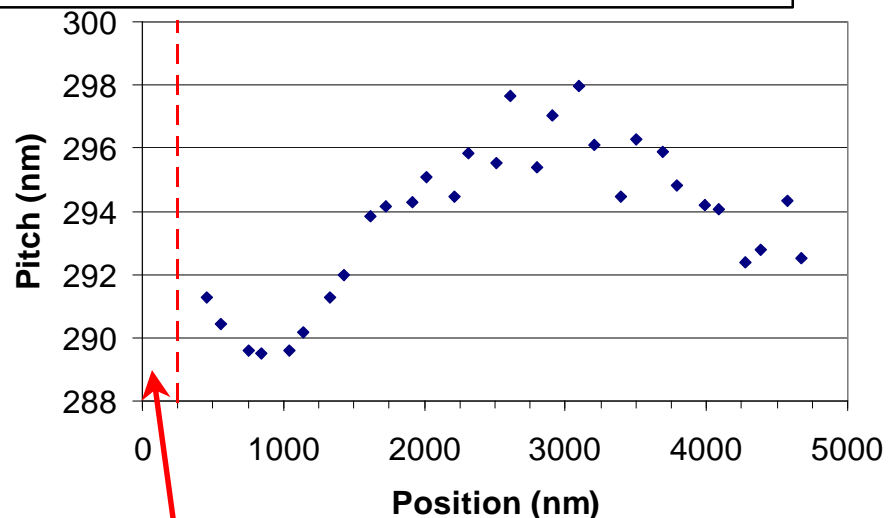
- ◆ NanoScope® IIIA, Dimension 3100, open-loop AFM (Veeco Metrology/Digital Instruments).
- ◆ We alternated scans of the calibration and test specimen.



- ◆ We analyzed height images using Advanced Surface Microscopy's DiscTrack Plus™ software.

AFM Measurement of Individual Pitch values

292 nm Standard (2 images)

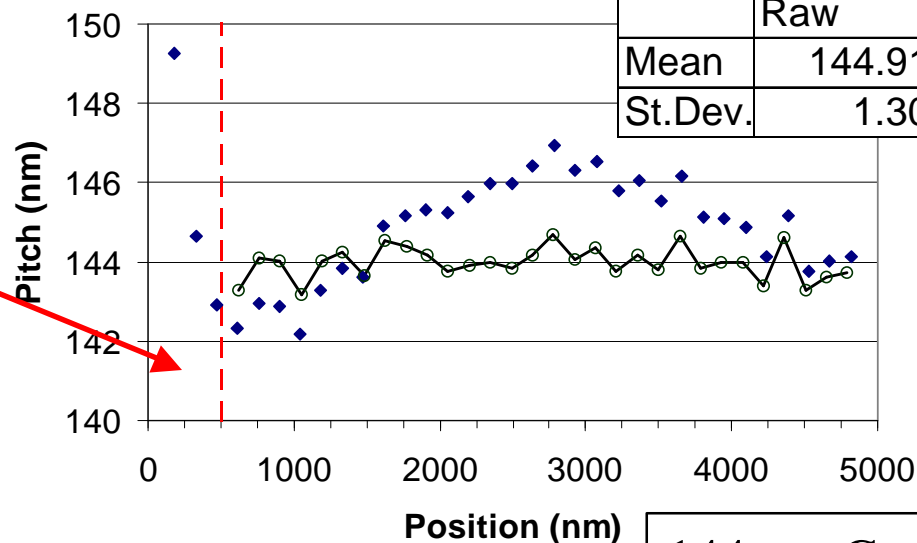


Data set has 3 images:

- Calibration Standard
- Test Sample
- Calibration Standard

“Bookend calibration”
corrects for short term
magnification drift.

Data exclusion
zone

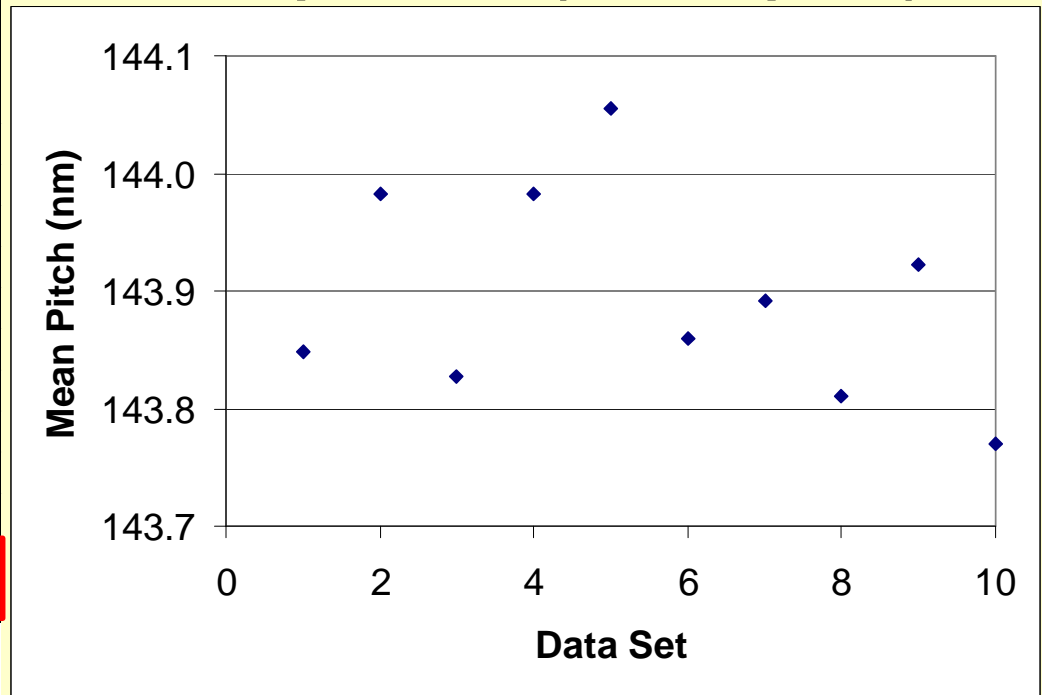


	Raw	Calibrated
Mean	144.91	143.98
St.Dev.	1.30	0.40

144 nm Grating (1 image)

AFM Results at 10 spots on Test Specimen (X Axis pitch)

Data Set	Count	Mean Pitch (nm)	Standard Deviation	Standard Deviation of Mean
1	30	143.85	0.42	0.08
2	30	143.98	0.40	0.07
3	30	143.83	0.55	0.10
4	30	143.98	0.64	0.12
5	31	144.05	0.69	0.12
6	31	143.86	0.58	0.10
7	31	143.89	0.50	0.09
8	30	143.81	0.55	0.10
9	31	143.92	0.55	0.10
10	30	143.77	0.59	0.11
Overall AFM Results		143.895	0.55	0.032



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

Optical Diffraction (OD) Proves AFM Accuracy

	Optical Diffraction (nm)	AFM Analysis (nm)	Difference (nm)
X direction	143.928	143.895	0.033
Y direction	143.931		33 pm WOW!
Uncertainty of mean(1 σ)	0.007 (0.005%)	0.039 (0.027%)	
Uncertainty of single pitch values (1 σ)	N/A	0.55 (0.38%)	

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

$\text{Sqrt}(7000/304) = \text{ca. } 5$. Ratio of uncertainties = ca. 5

Picometer Precision

- ◆ To qualify microscopes and prospective calibration standards:
- ◆ Measure pitch in 1 or a few images using self-calibration.

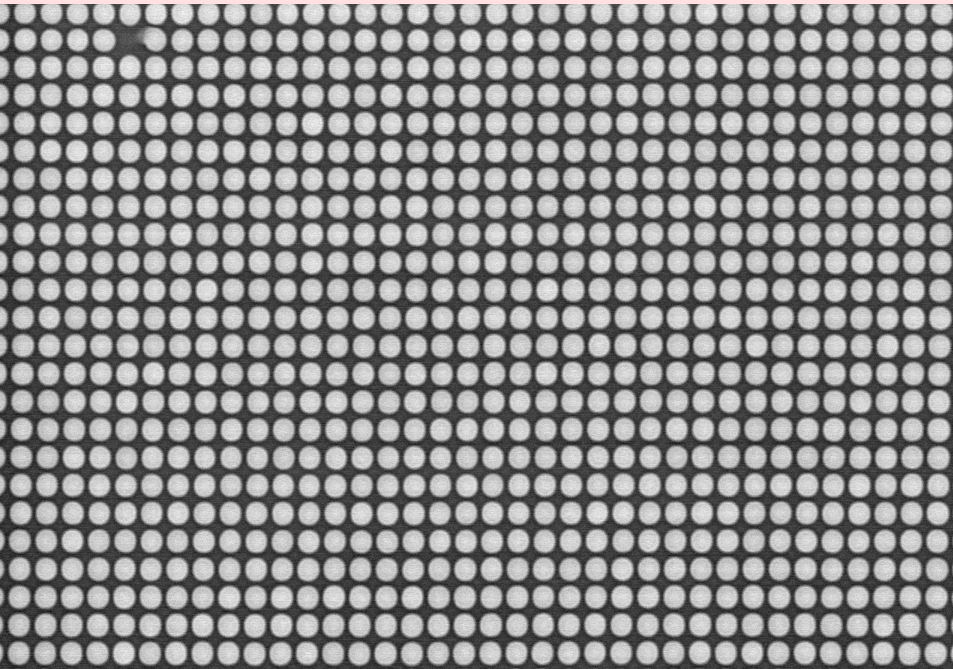
SEM Pitch Measurements of 144 nm Grid - Precision

SEM: Hitachi S4700 at 5 kV.

$\sigma = 0.43$ nm.

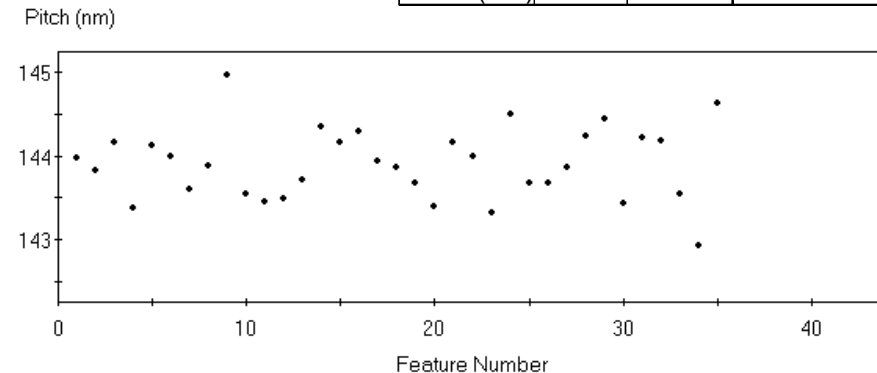
Relative $\sigma = \sigma / \text{mean} = 0.30\%$

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



Pitch Values

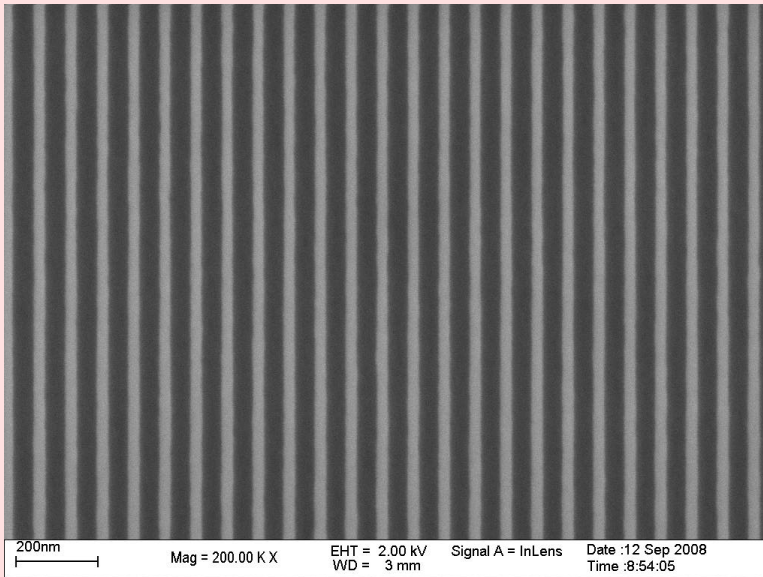
	Count	Mean	Std.Deviation
Pitch (nm)	35	143.90	0.43



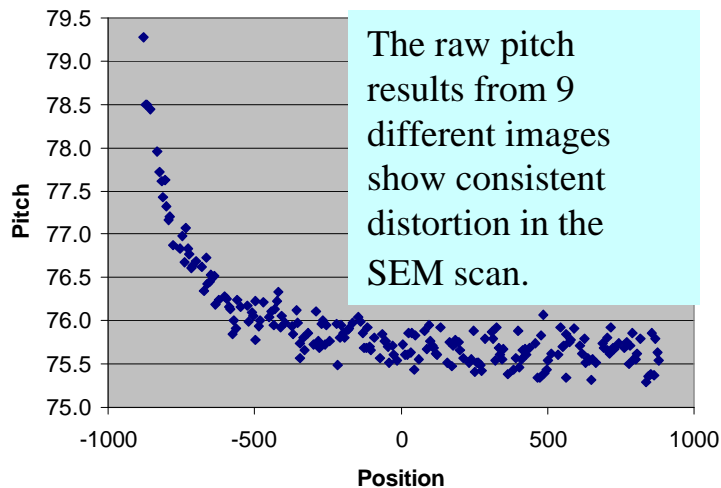
Calibration files: 5kV25kxSEMcropped.tif.asm
data files: 5kV25kxSEMcropped.tif.asm

SEM of 76 nm 1-D Grating

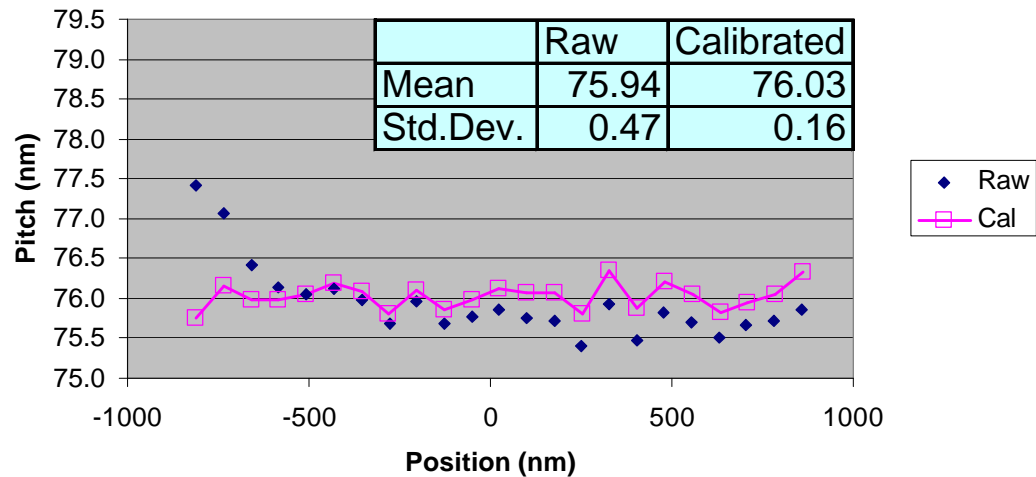
- ◆ SEM - Zeiss Supra 55VP
- ◆ Relative $\sigma = 0.21\%$



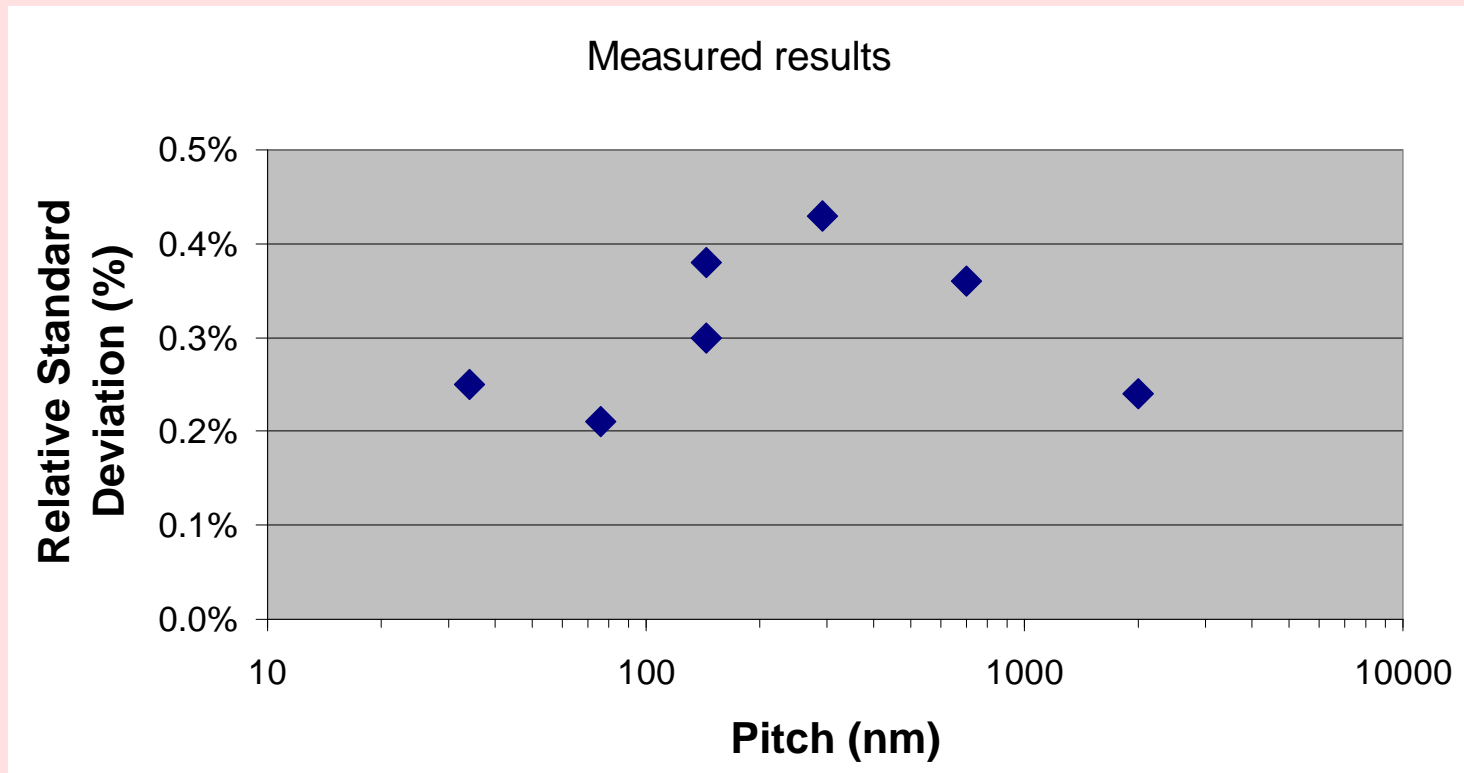
200 kX raw Pitch (nm)



Raw and Calibrated Pitch for 1 image



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.

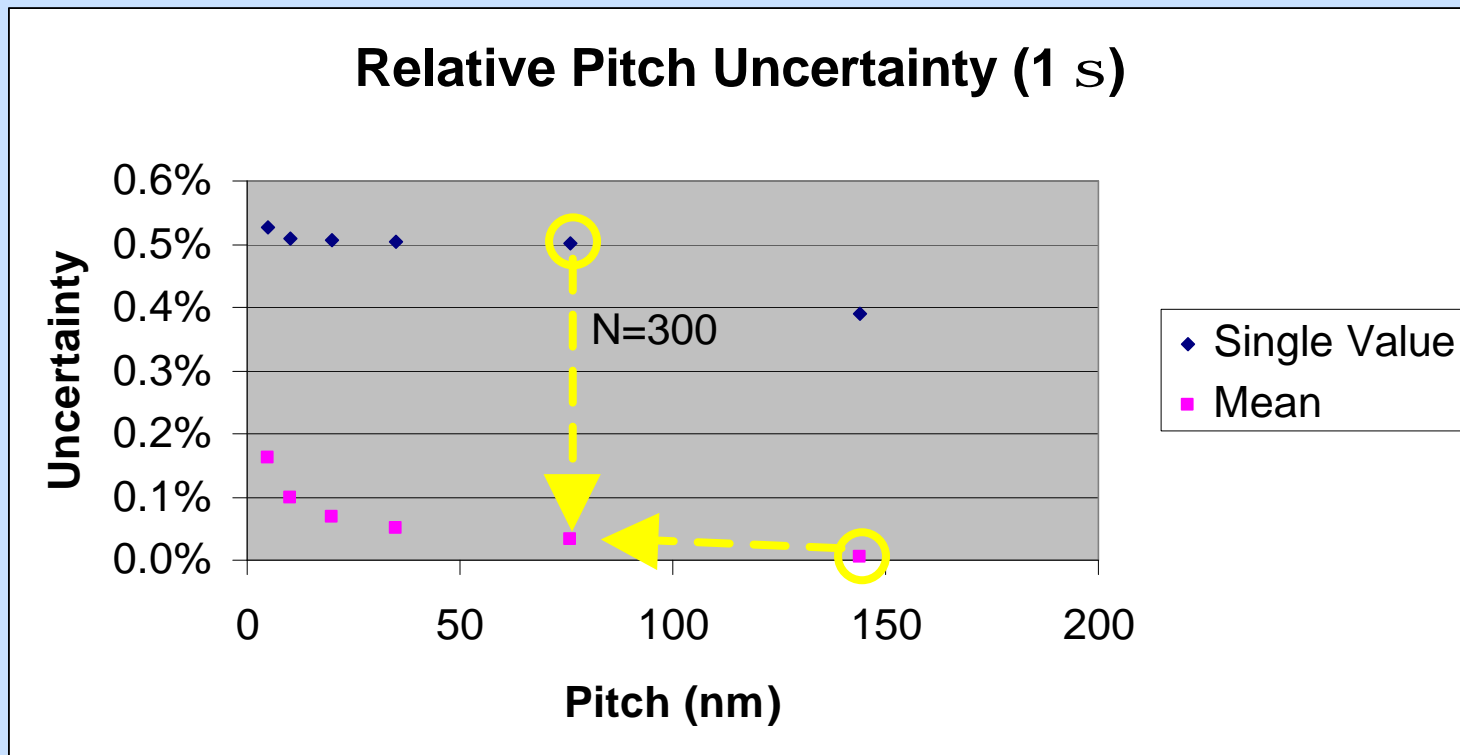
- ◆ 144 calibrates 76

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).

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.