

Picometer-Scale Accuracy in Position Measurements of NanoDots in a 525 G dot/in² Pattern

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Abstract

Patterned magnetic media require nanometer control of track pitch and feature size variation. Nanometer control implies picometer metrology. We use an ordinary open-loop AFM with additional offline calibration and measurement software to measure pitch and pitch variation. In systematic measurements on a 144 nm pitch 2-Dimensional square grating (31 G dot/in²) we measured individual pitch variation of 0.55 nm (1 σ) and average pitch to an accuracy of 40 pm (1 σ). Accuracy was confirmed by optical diffraction measurements at a national standards laboratory.

SEM of a 76 nm pitch 1-dimensional grating (334k tracks/in) showed individual pitch variation of 167 pm (1 σ).

SEM of a 35 nm pitch 2-dimensional grating (525 G dot/in²) showed individual pitch variation of 80 pm (1 σ). This precision suggests we can measure the average pitch to an accuracy of 10 pm (1 σ). We also report pattern angle and skewness with precision better than 0.1°.

Metrology Requirements for Patterned Media

Media Type	Removable?	Track Pitch Variation (% of Pitch, 1 σ)	Required Gauge Precision (% of Pitch, 1 σ)	Next generation track pitch (nm)
Optical	Yes	1-1.5%	0.33-0.5%	100-150
Patterned Magnetic Media	No	3-6%	1-2%	25-50

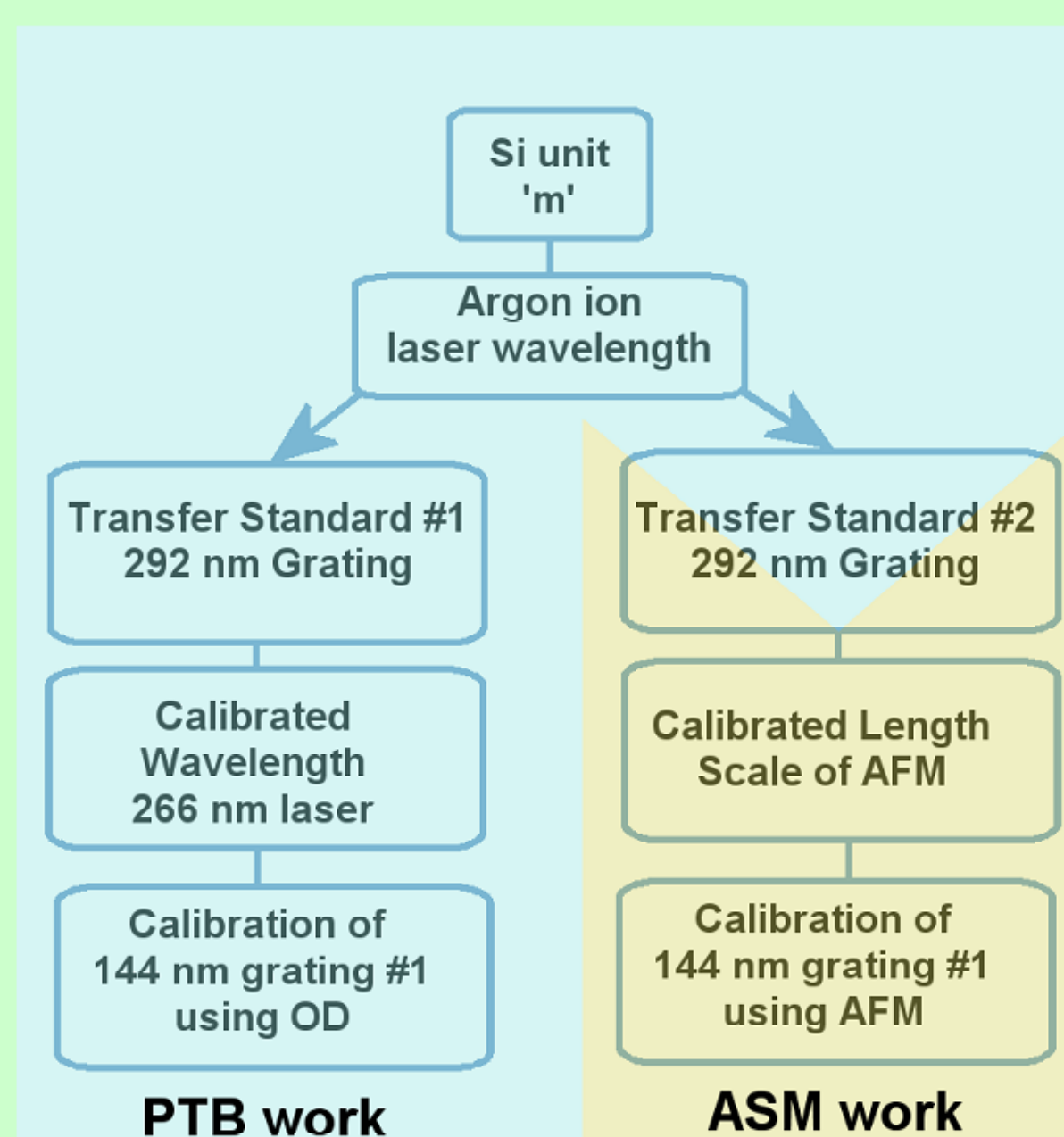
Objectives:

- Show that “ordinary” AFM or SEM can meet the requirements, such as measuring a perfect 150 nm pattern with $\sigma < 0.75$ nm or a 50 nm pattern with $\sigma < 0.5$ -1 nm
- Show that traceable calibration standards can be qualified with pitch values < 50 nm and with useful uncertainty limits.
- Demonstrate the measurement of size and position parameters.

Part 1: Picometer Accuracy

Materials and Methods—Traceability Path

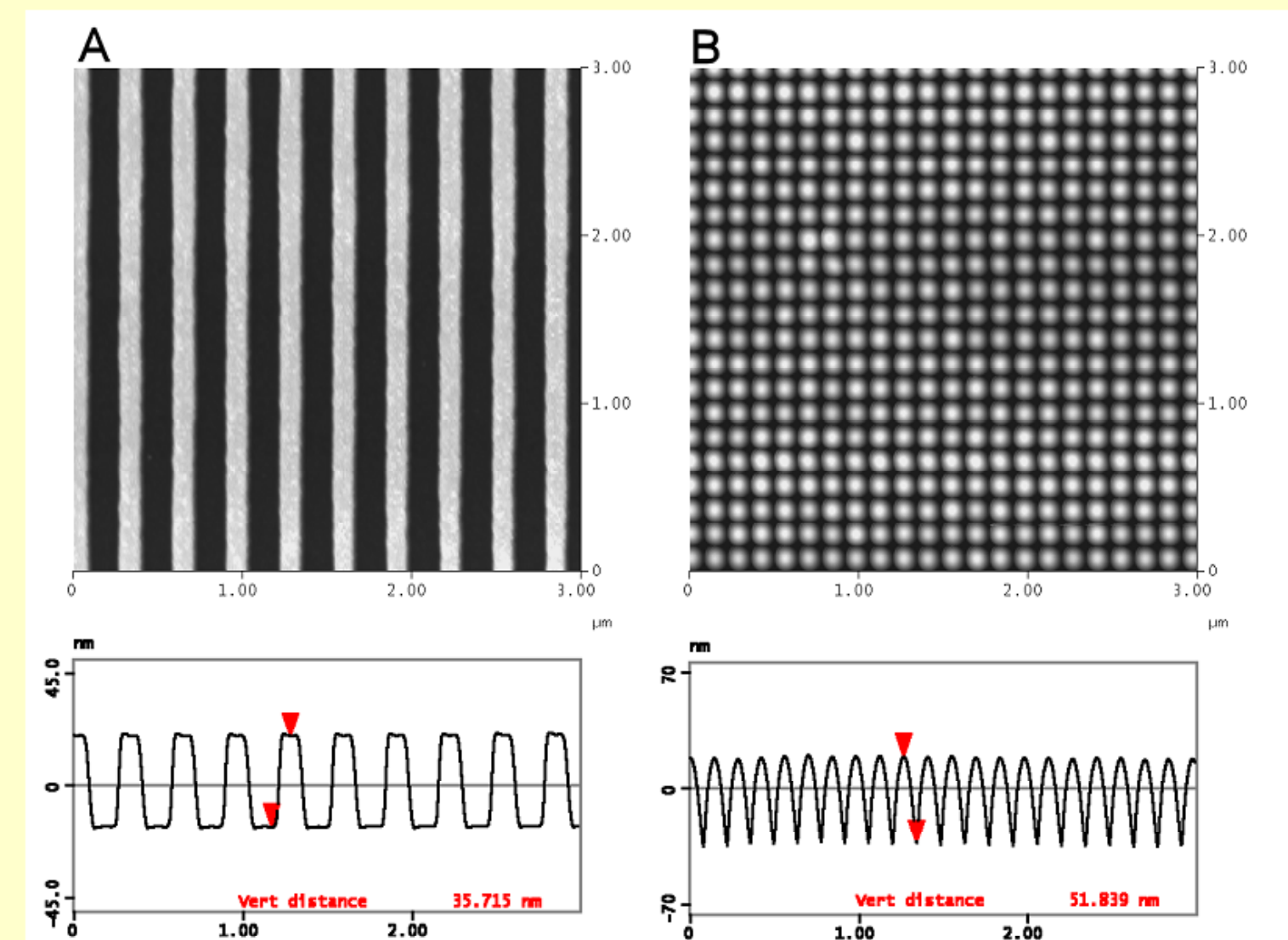
- Physikalisch-Technische Bundesanstalt (PTB) used optical diffraction (OD) to measure the mean pitch of the gratings.
- At Advanced Surface Microscopy (ASM) we used atomic force microscopy (AFM) to measure individual pitch values, which led to mean values and standard deviation.



Materials and Methods—Test Specimens

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

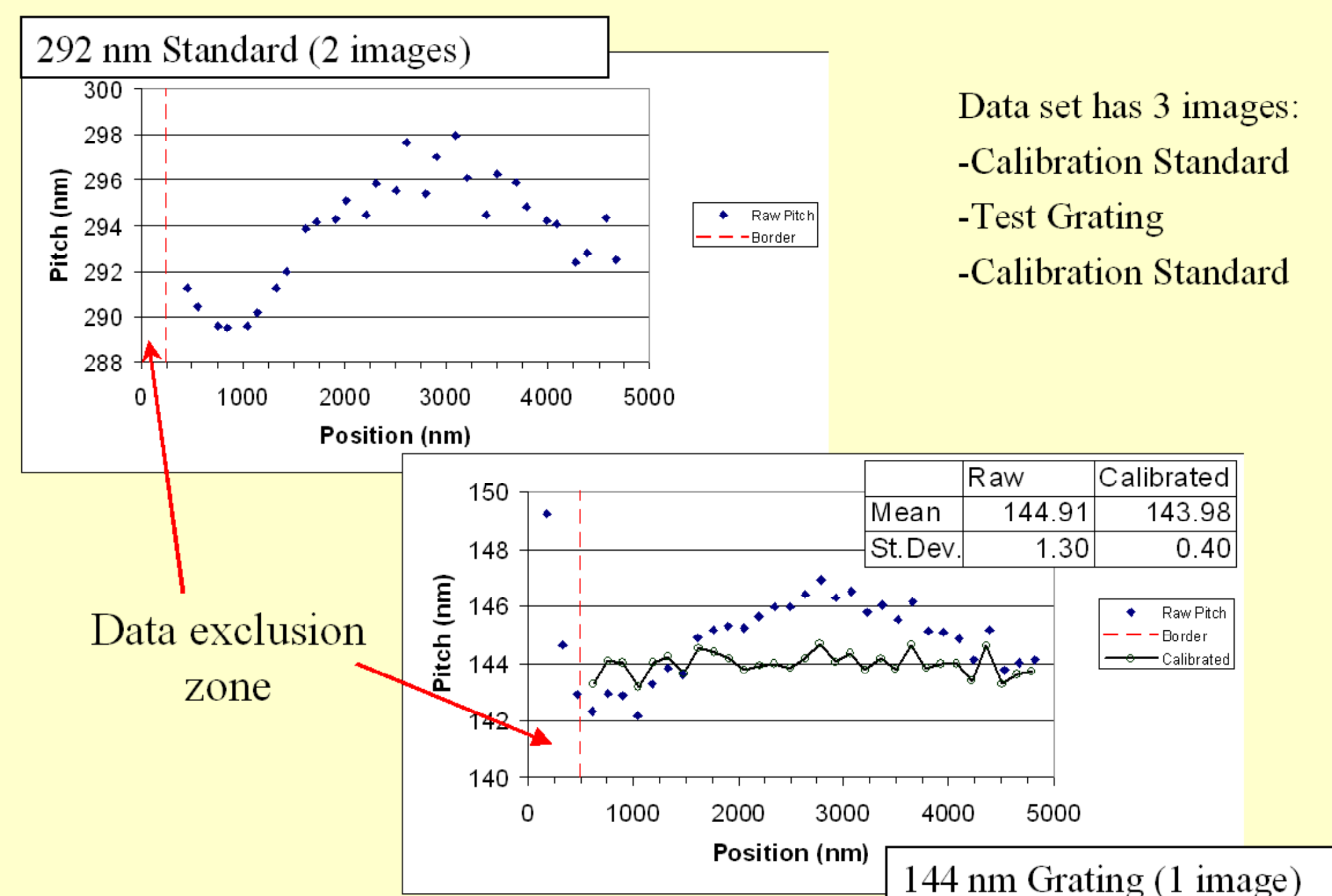
144 nm Pitch, 2D, Al on Si
(Height: 88 nm,
column average height 52 nm)



AFM Data Capture and Analysis

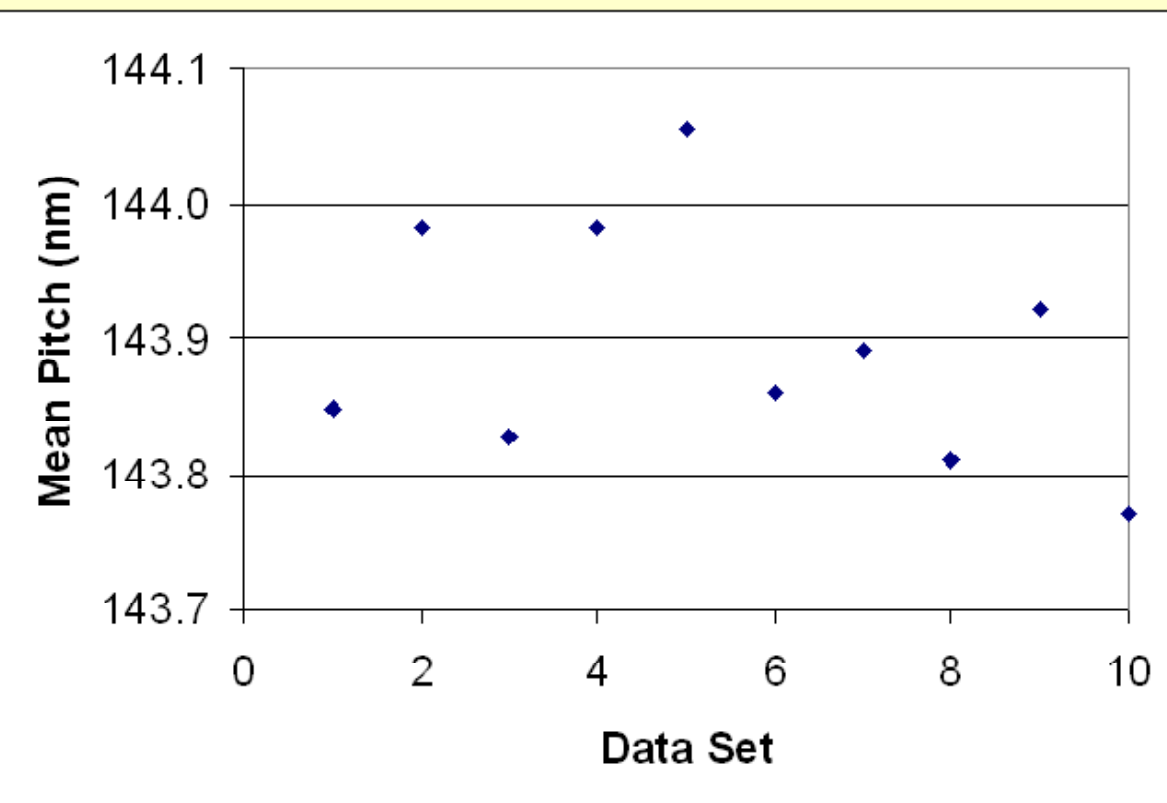
- NanoScope® IIIA, Dimension 3100, open-loop AFM (Veeco Metrology/Digital Instruments).
- Calibration standard Model 301BE/292UTC calibrated previously at PTB (Pitch 292.096 \pm 0.015 nm 95% confidence interval).
- Test specimen Model 150-2DUTC calibrated at PTB (results below).
- We interleaved scans of the calibration and test specimen.
- We analyzed height images using Advanced Surface Microscopy’s DiscTrack Plus™ software.
- Each data set consisted of one test specimen image and two images of the calibration standard, one captured before and one captured after the test image. This procedure (“interleaved calibration”) increases accuracy by correcting for short term drift in the AFM’s magnification and it increases precision by using redundant calibration data.

AFM Measurement of Individual Pitch values



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 closely, and the difference is mainly due to random error in individual pitch measurements.

Part 2: Picometer Precision

SEM Pitch Measurements of 144 nm Grid - Precision

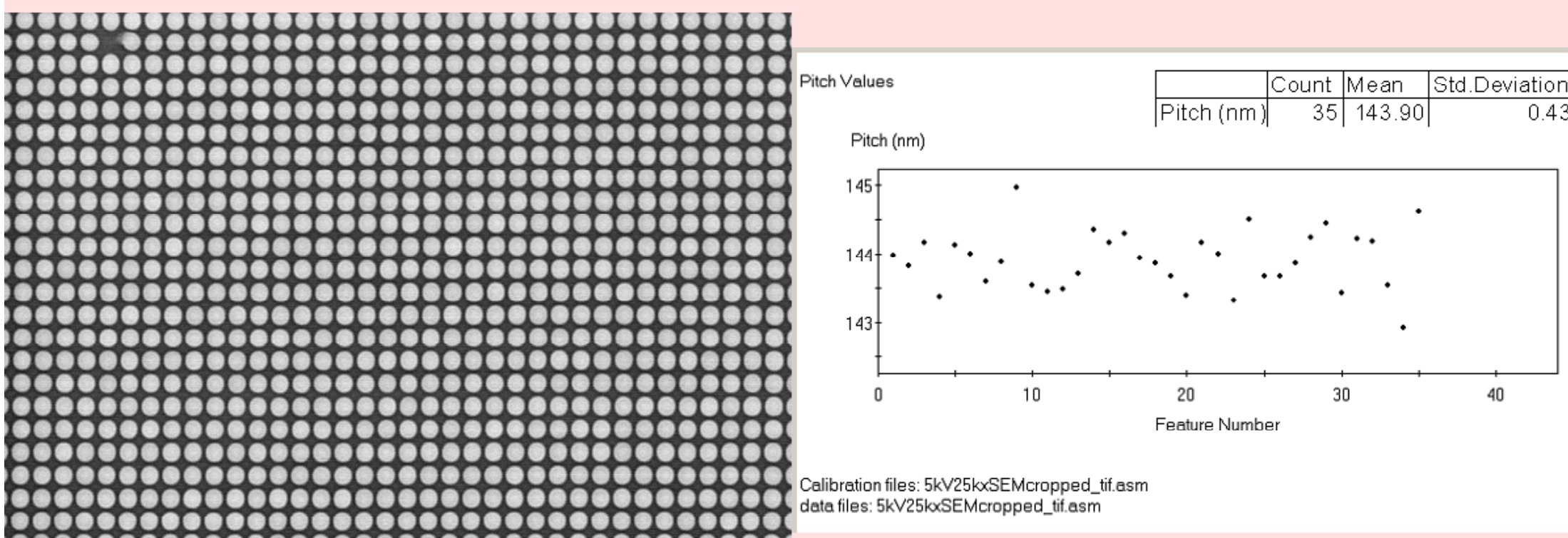
SEM: Hitachi S4700 at 5 kV.

To measure precision of single pitch values, we calibrated the image with itself.

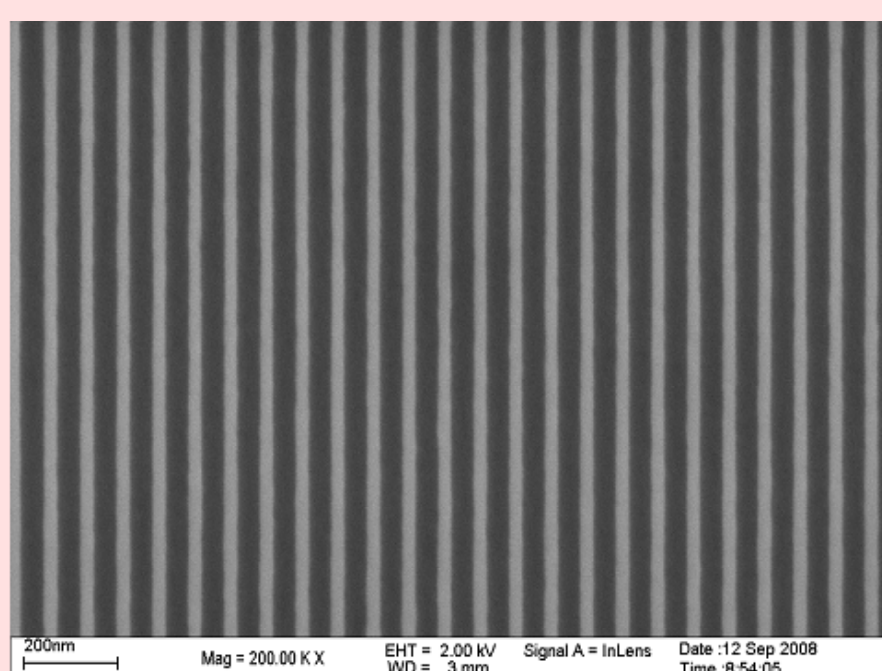
$\sigma = 0.43$ nm.

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

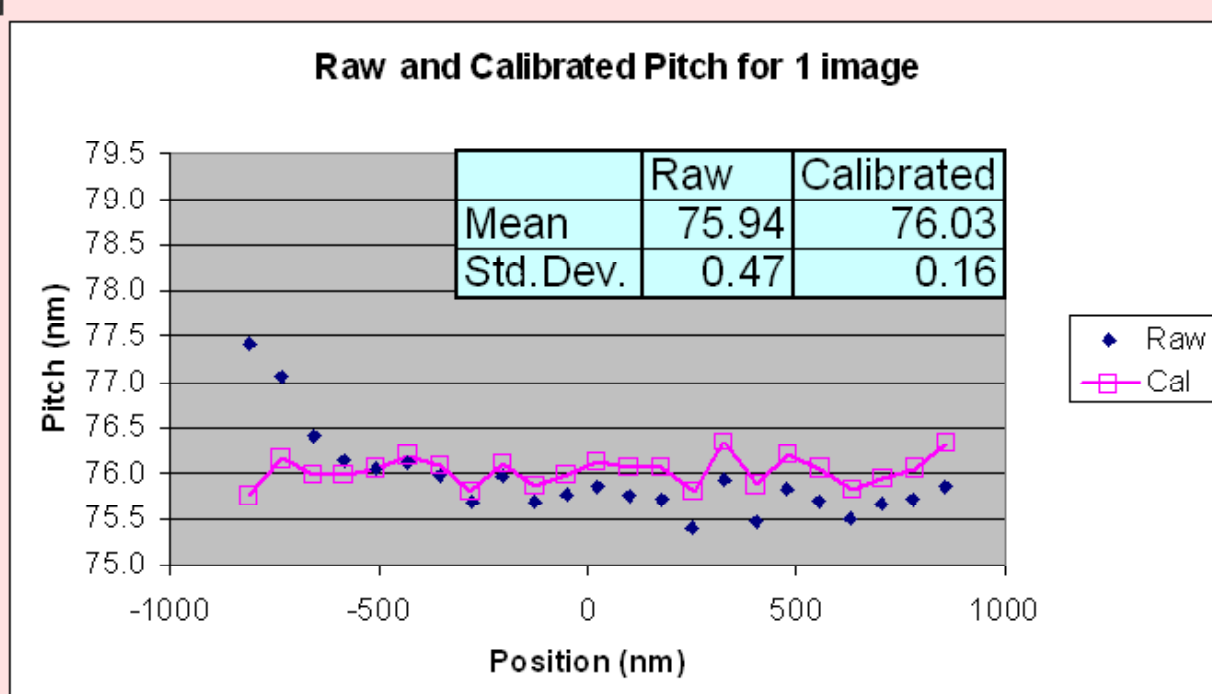
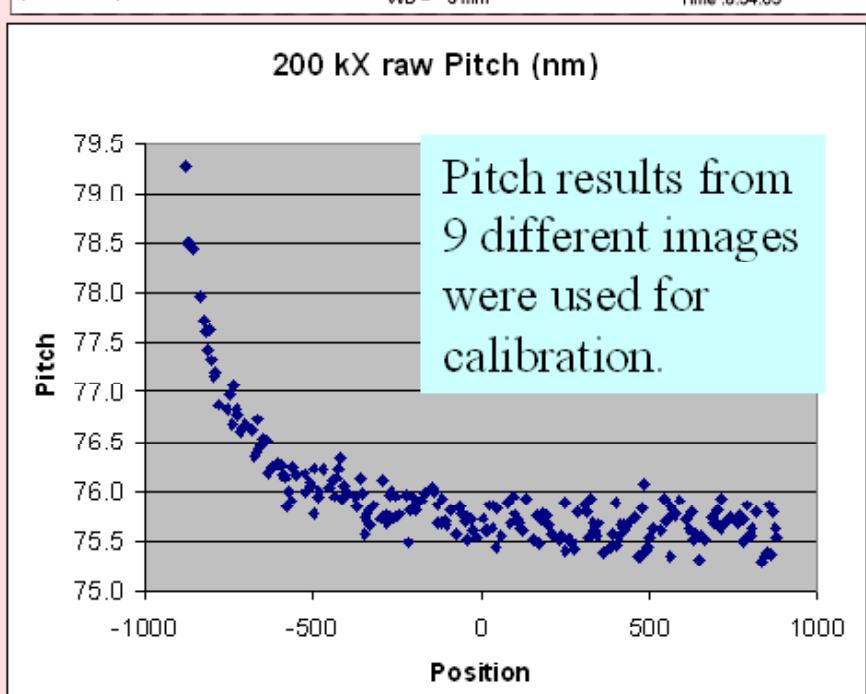
Field Emission SEM and AFM have similar precision for pitch measurements.



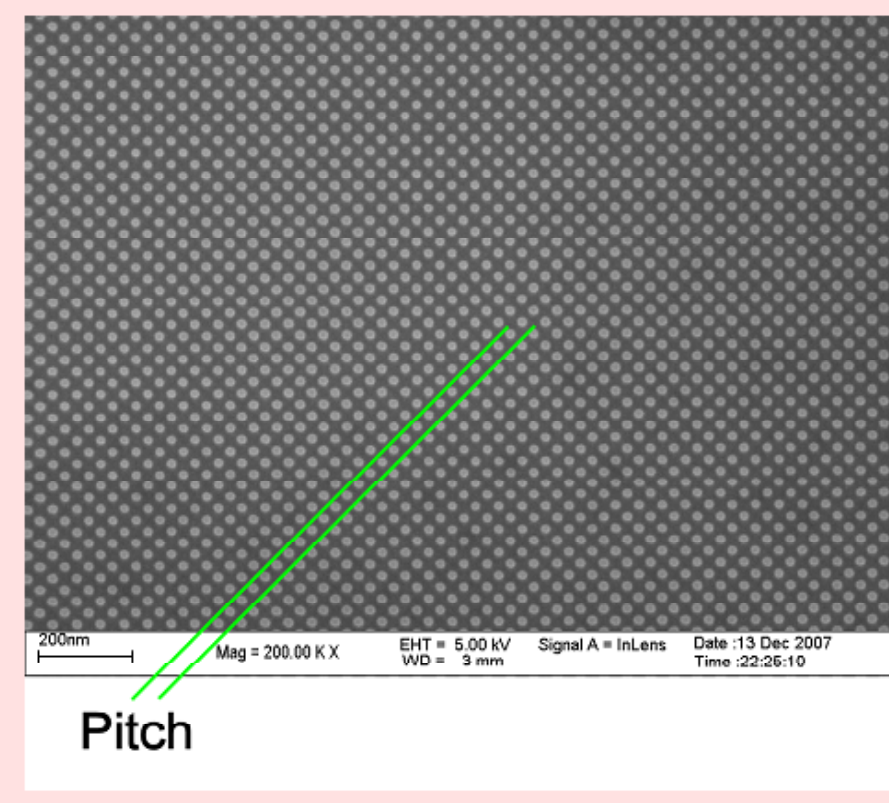
SEM of 76 nm 1-D Grating



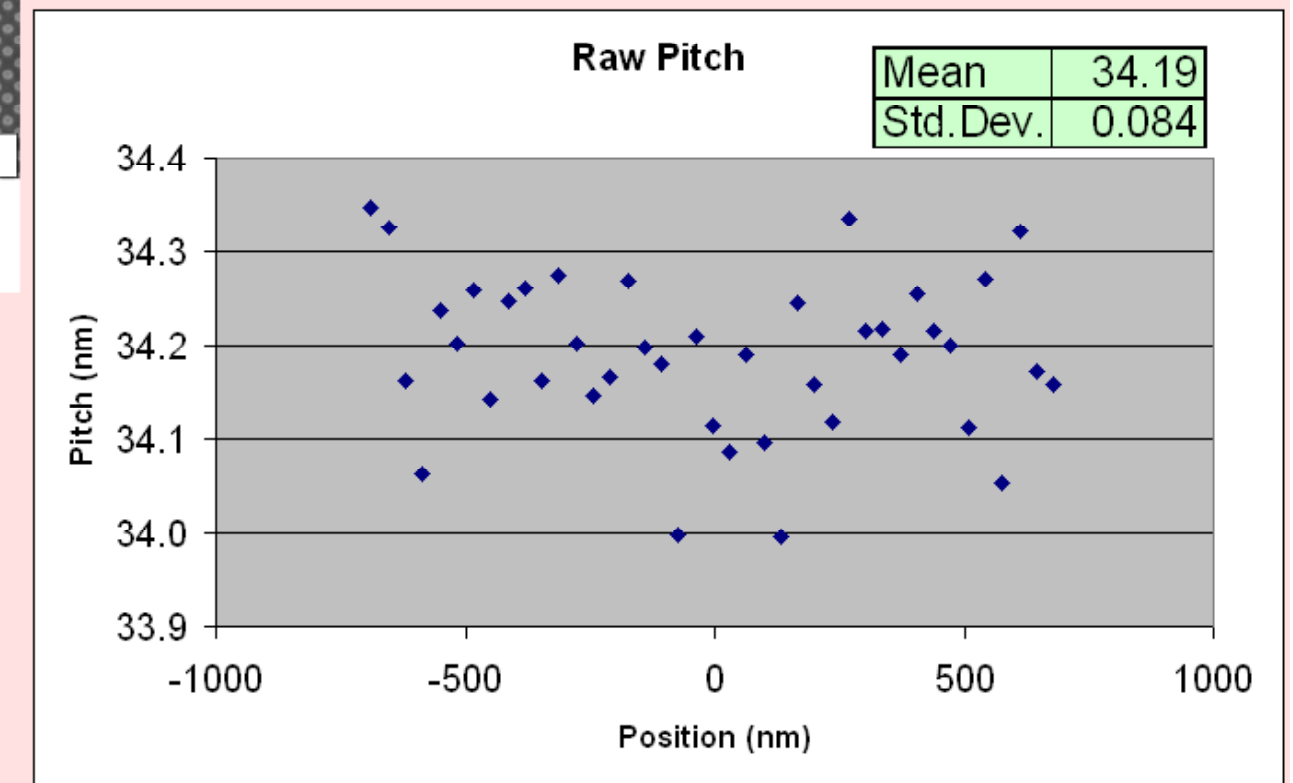
- HSQ resist on Silicon, fabricated by Extreme UV interference lithography.
- SEM - Zeiss Supra 55VP
- Relative $\sigma = 0.21\%$
- Image courtesy of Harun Solak (Eulitha AG)



35 nm Pitch, 2-D grid (525 G dots/in²)

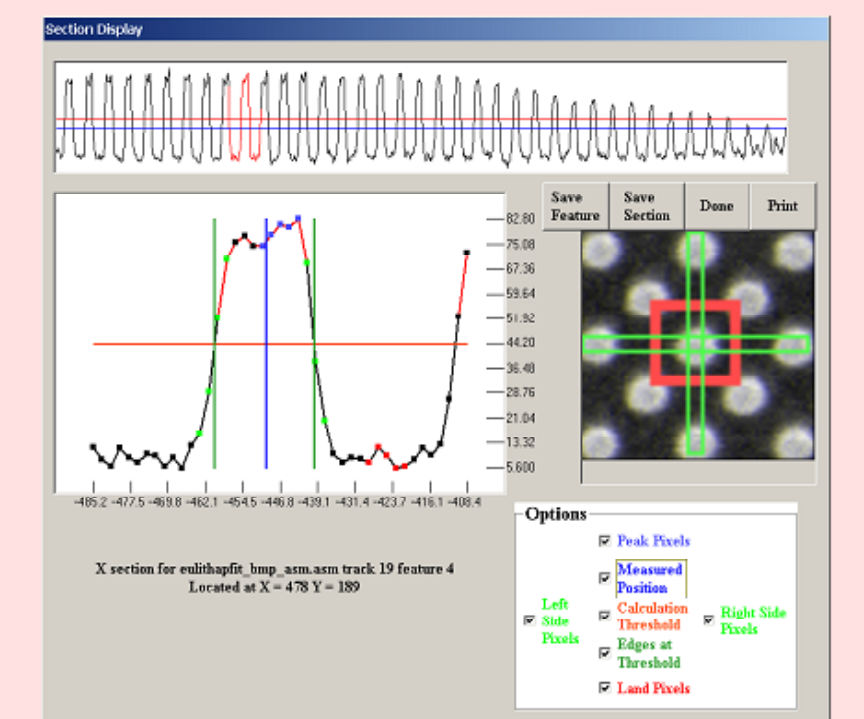
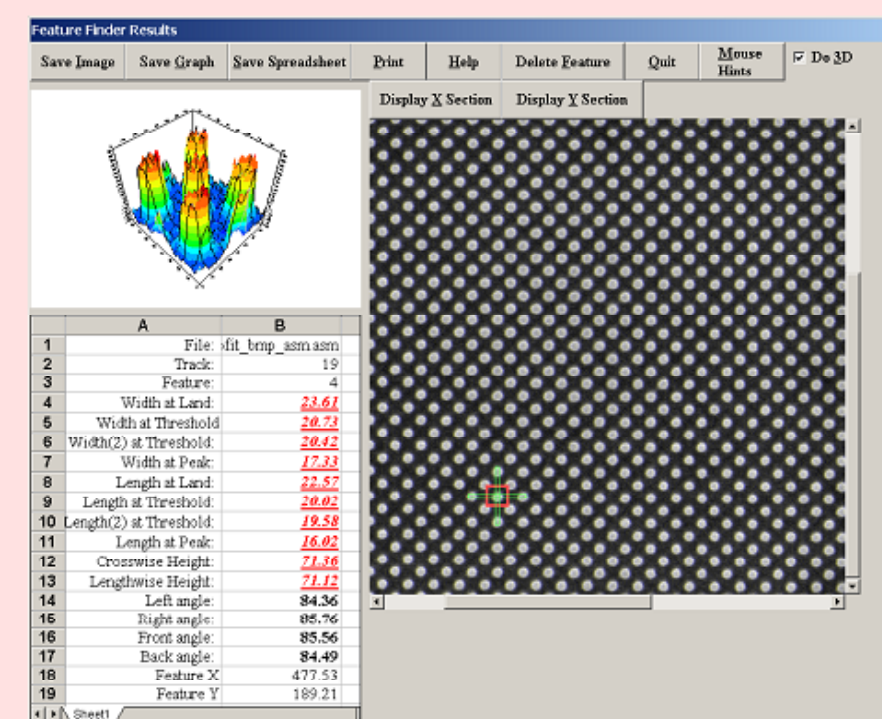
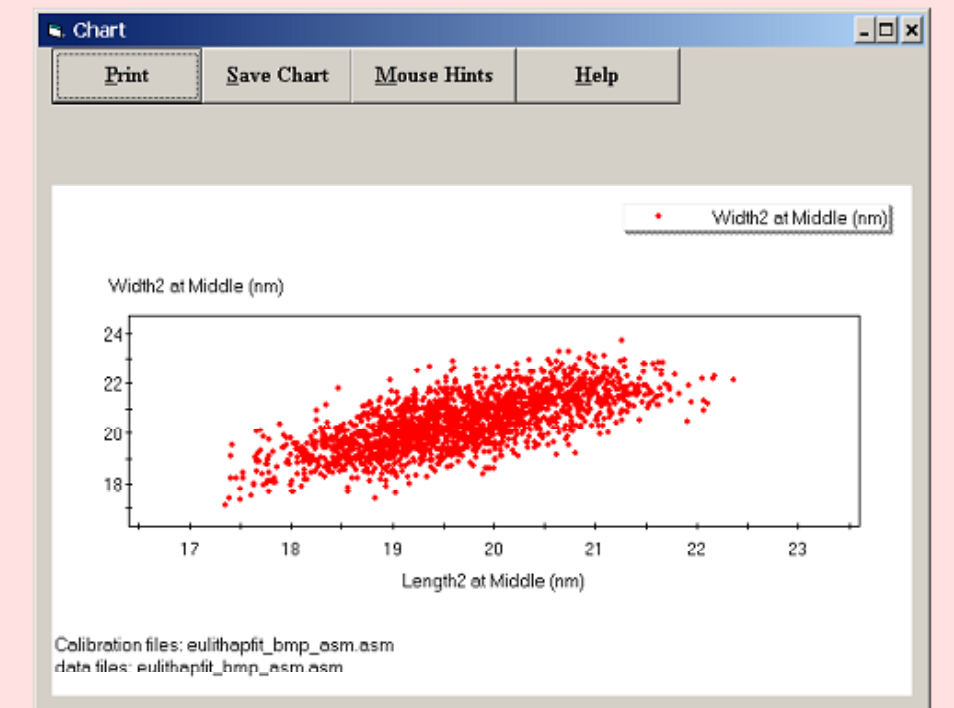


- HSQ resist on Silicon, fabricated by Extreme UV interference lithography.
- SEM - Zeiss Supra 55VP
- Relative $\sigma = 0.25\%$ (uncorrected, raw data)
- Image courtesy of Harun Solak (Eulitha AG)

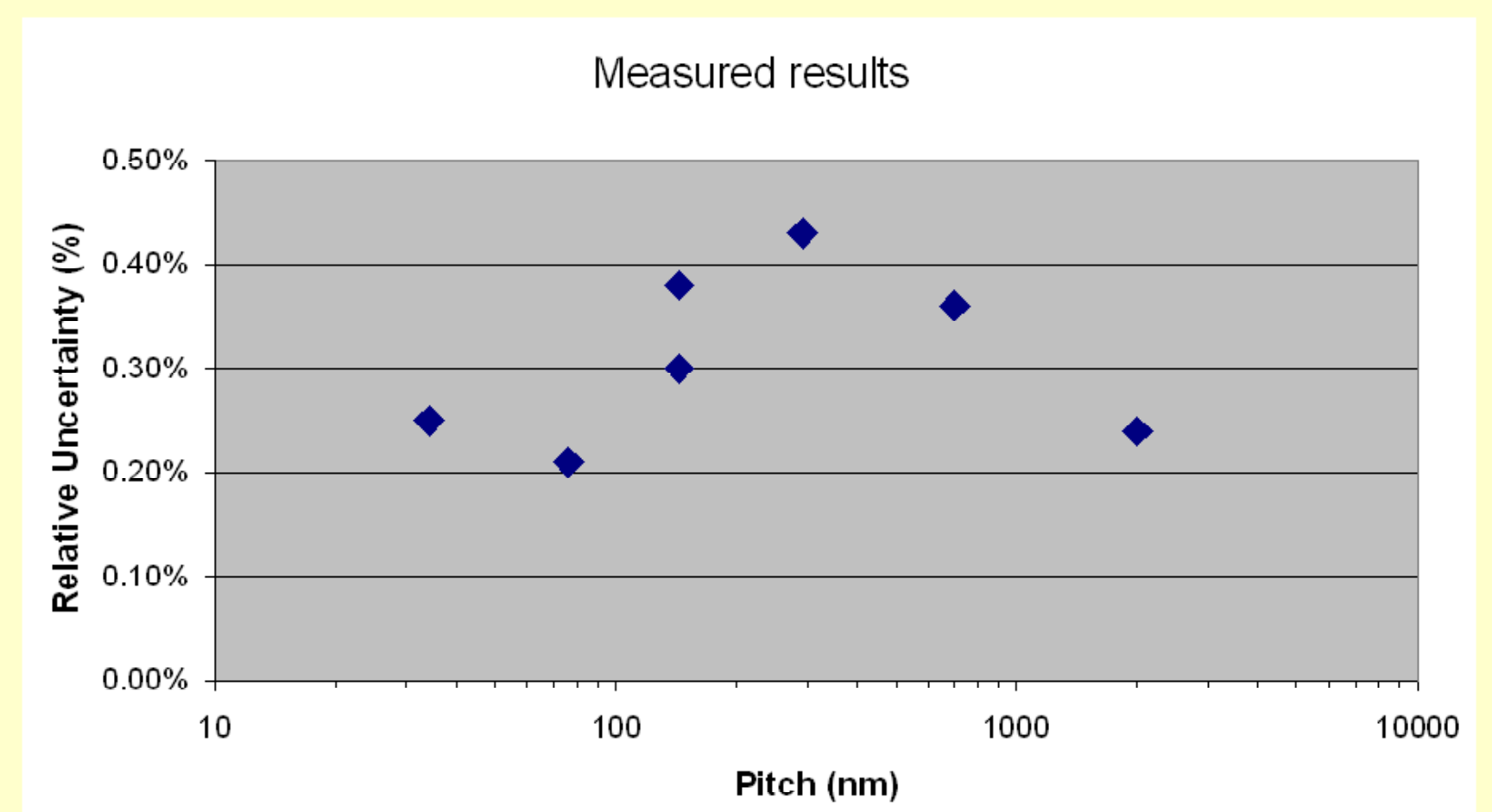


Bump Widths and Lengths (from SEM data)

	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



Summary: Precision of AFM and SEM Pitch Measurements



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.

Conclusions

- The AFM and Optical Diffraction (OD) measurements of mean pitch differed by only 33 pm, which is less than the 95% confidence interval (80 pm) for the comparison. This assures that the AFM can produce accurate, traceable pitch measurements.
- Using OD measurements as a high-accuracy foundation for pitch metrology, we got high precision measurements of pitch variation using a general purpose microscope (here, an ordinary AFM).
- AFM and SEM precision at 144 nm meets the metrology requirements for optical disc.
- We extended this Metrology to smaller pitch. SEM precision at 76 and 35 nm meets the requirements for HDD. (AFM will be tried soon.) Optical diffraction with the current setup at PTB is limited to pitch > 140 nm. However, general purpose microscopes will extend the range of traceable calibration specimens to 50 nm and below, with expanded uncertainty of mean pitch < 0.1% of the pitch value.

Please visit Booth 523
Attend our live demo in the Innovation
Zone. Wednesday 11-1130 AM



Don Chernoff

