Ultraprecision CD Metrology for Sub-100 nm Patterns by AFM

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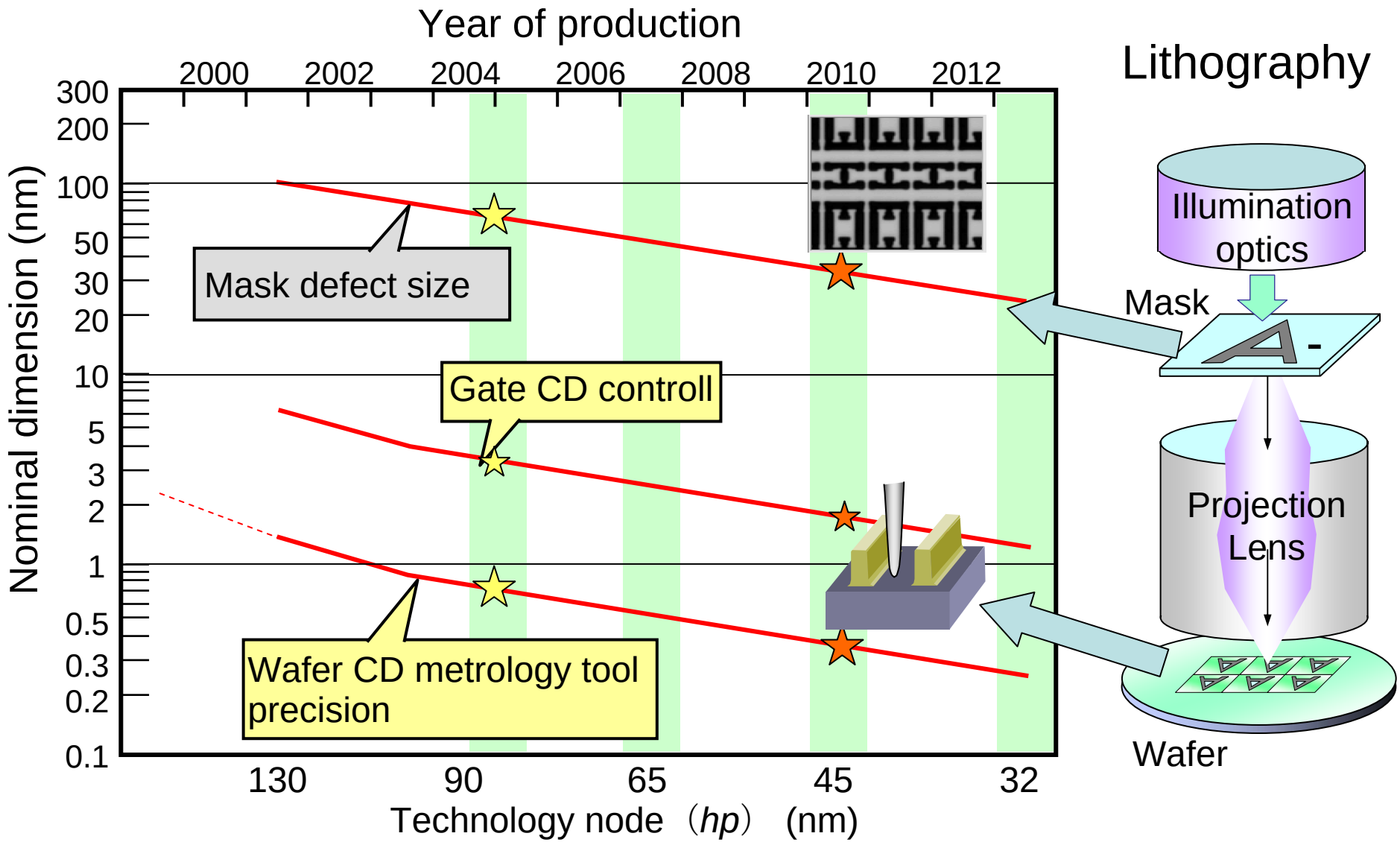
Outline

1. *Introduction*

2. *Metrological AFM design*
   Novel 3D scanner, compact laser interferometers
3. *Interferometer performance*
   Resolution / linearity
4. *Apparent linewidth repeatability*
   Optimization / preliminary demonstration
5. *Stage positioning*
   Optimization / minimization of drift
6. *Summary and future work*

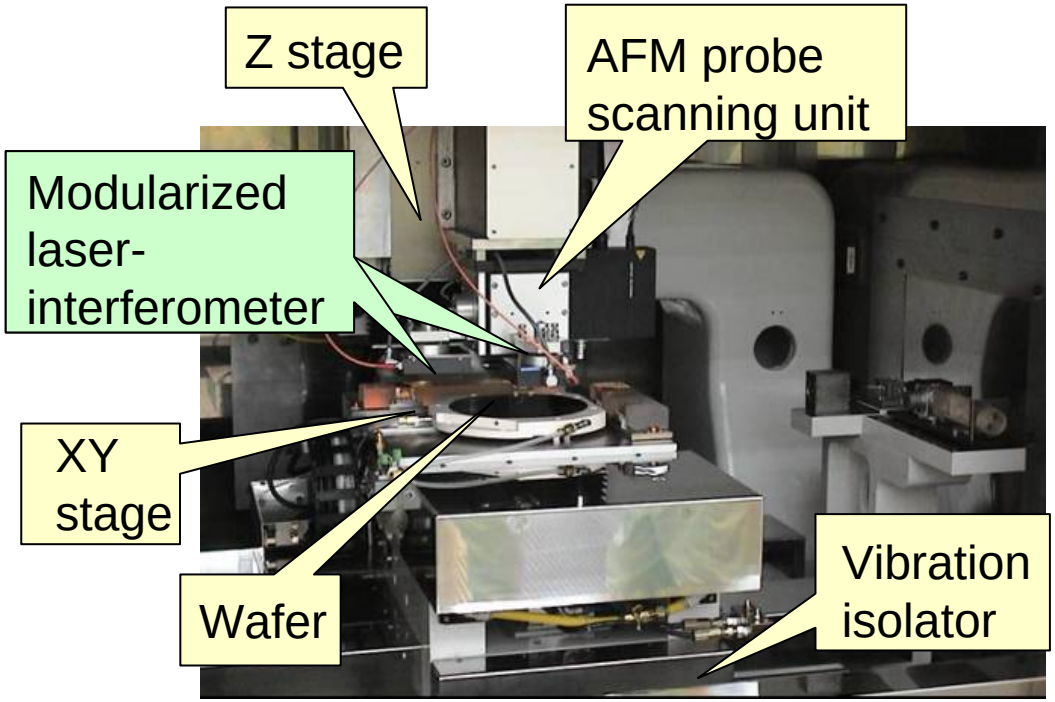
Lithography requirements



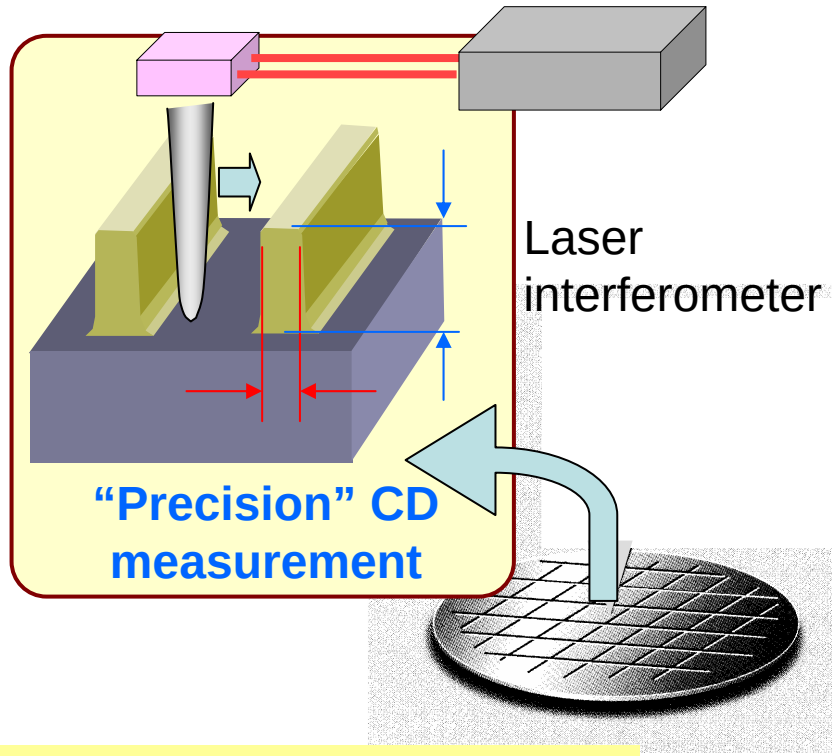
Metrological improvement in AFM

Category	*Items to be solved*
AFM tip	Radius of curvature, Tip artifact, Tip wear / broken
Scanning technology	Straightness, Orthogonality, Mechanical vibration, Scheme of servo control
Linearity	Resolution / precision of displacement sensor
Profile analysis	Deconvolution of profile data, Definition of CD
Environment control	Floor vibration, Acoustic noise, Temperature fluctuation

MIRAI AFM Set up



AFM probe scanner and mirror



Goal:

Development of precision AFM for nanometer-scale dimensional measurement :

Tool precision: 0.3 nm in 2007

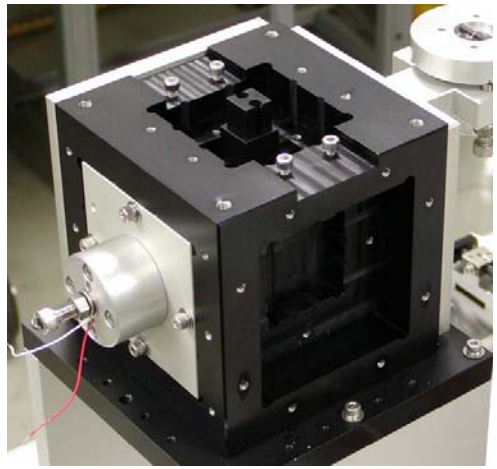
Configuration of AFM unit

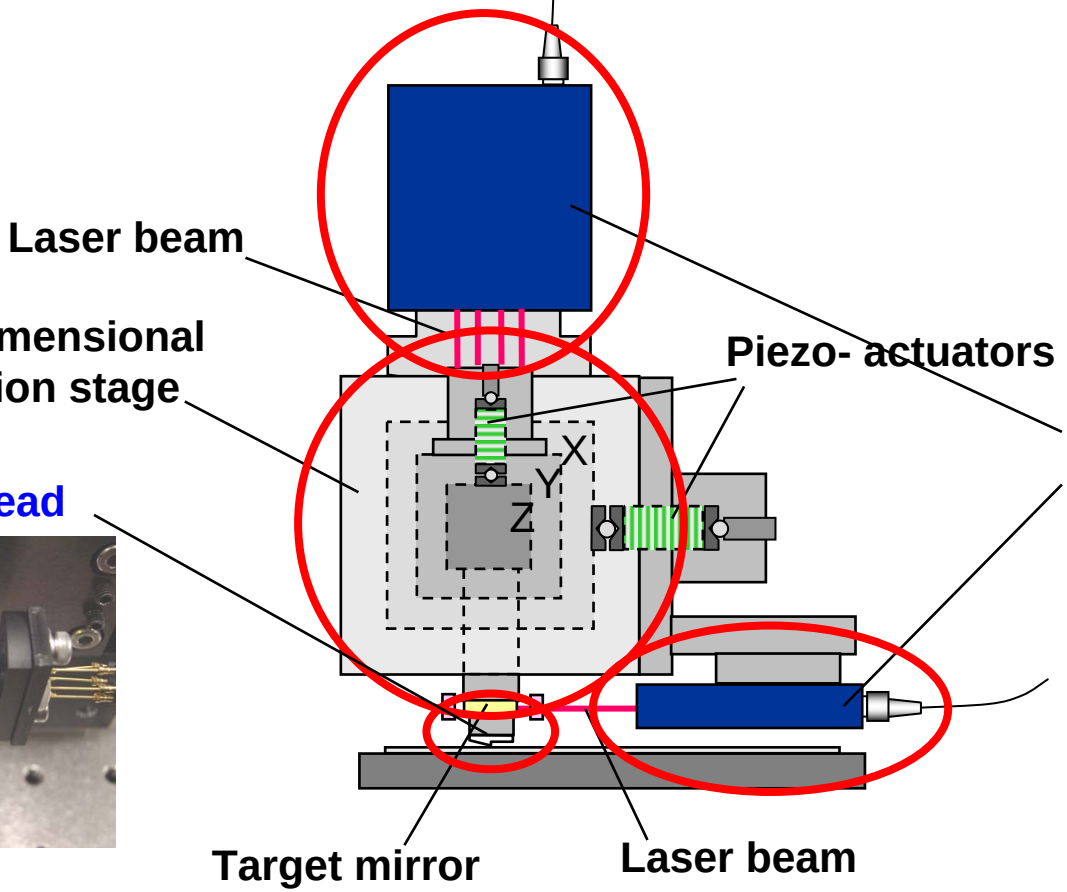
**Compact AFM head enables quick response to atomic force*

**Highly straight, independent motion along XYZ axes*

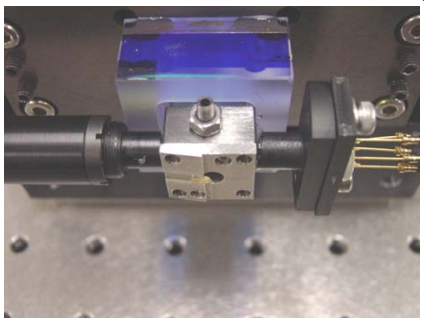
**High-resolution displacement monitoring*

Monolithic 3D scanner

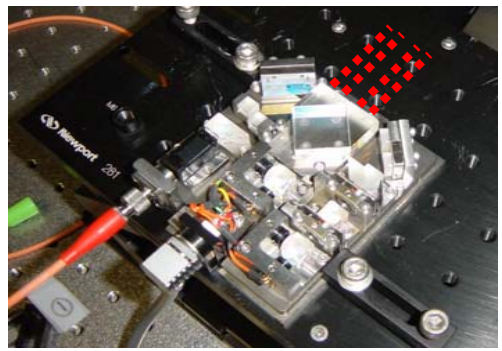




Miniaturized head



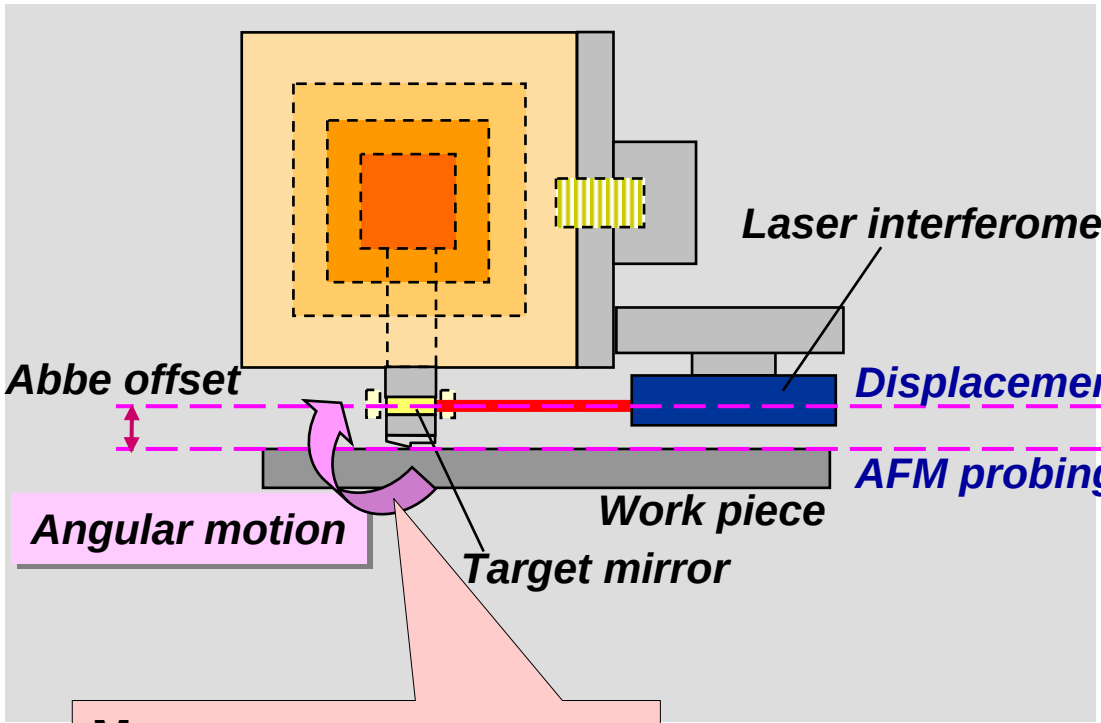
Modularized laser interferometer



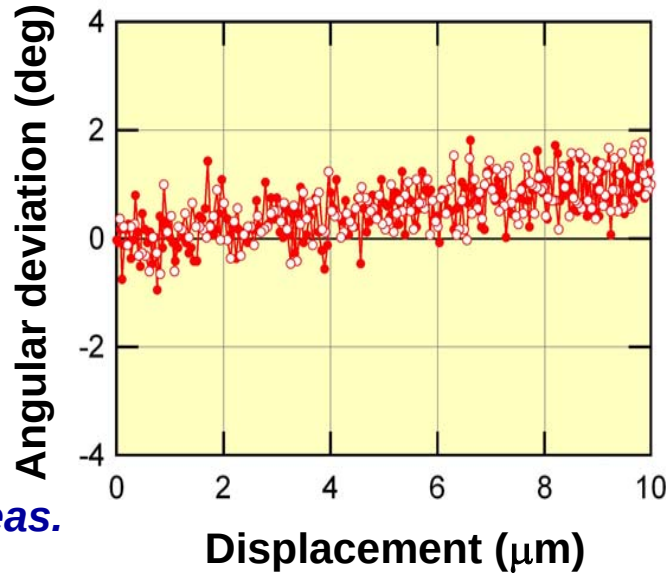
Uncertainty consideration in angular motion

Difference between axes of displacement measurement and AFM probing

Angular motion yields measurement error of displacement



Meas. error
= $\Delta\theta$ x (Abbe offset)



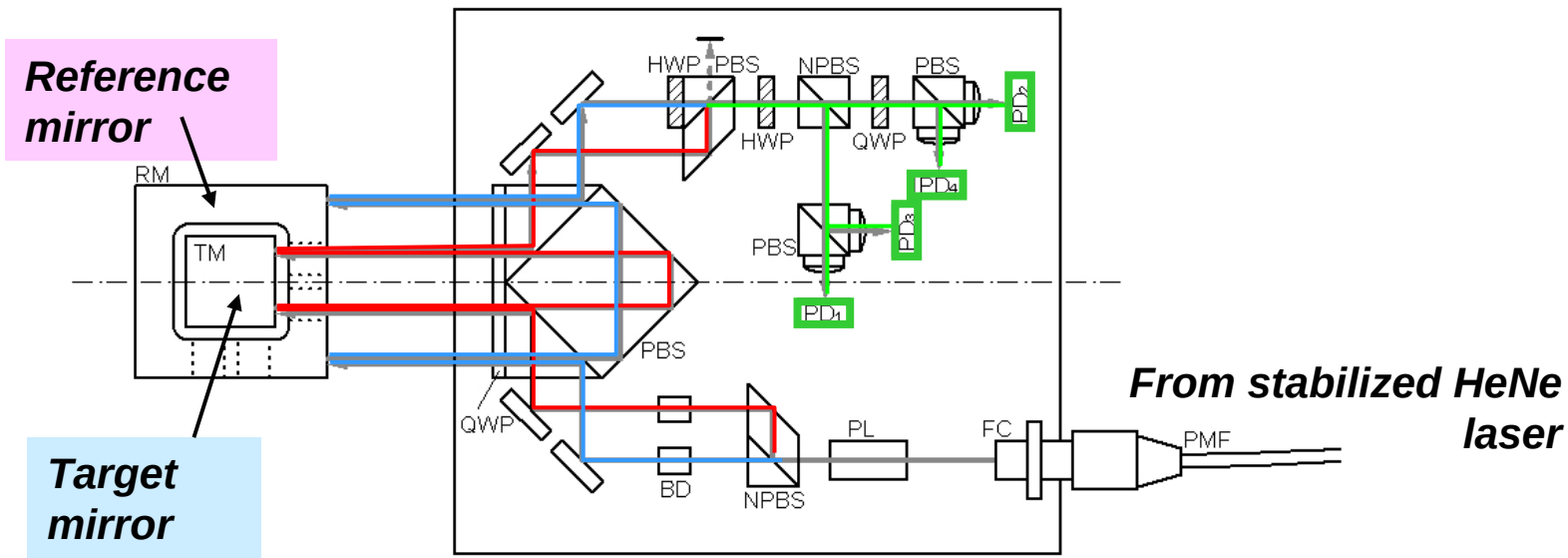
Estimated measurement error for 100 nm :

0.2 nm max.

***Correctable if necessary**

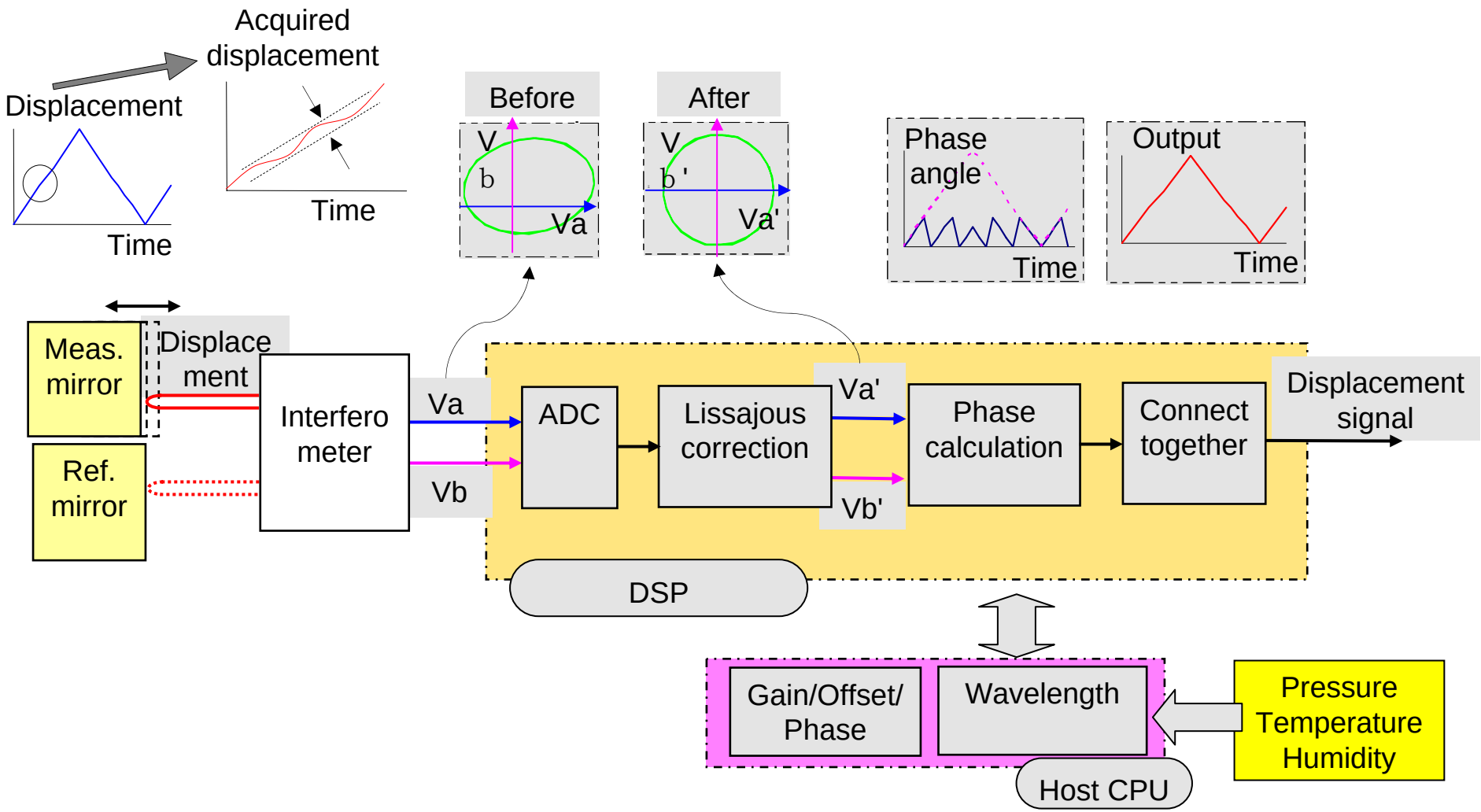
Optical design of interferometer

- *differential scheme*
- *double pass*
- *Michelson type*
- *homodyne*
- *wavelength is calibrated ($\Delta \sim 10^{-9}$)*

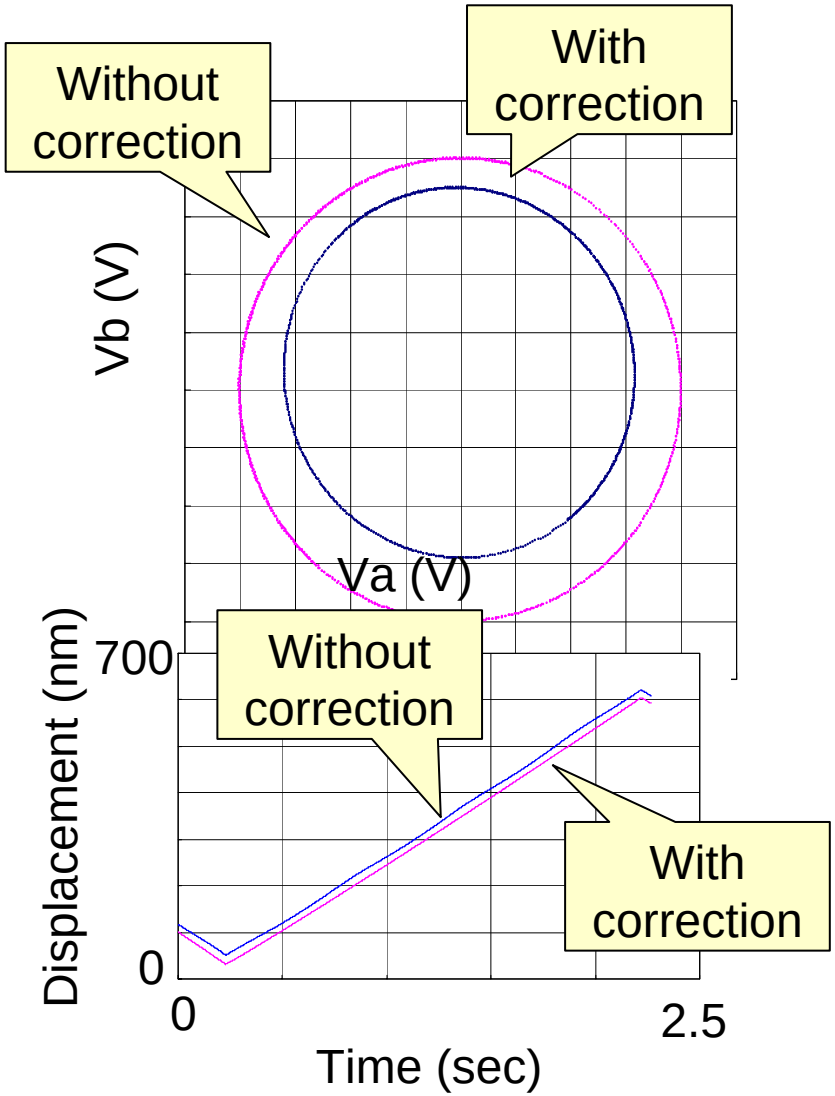


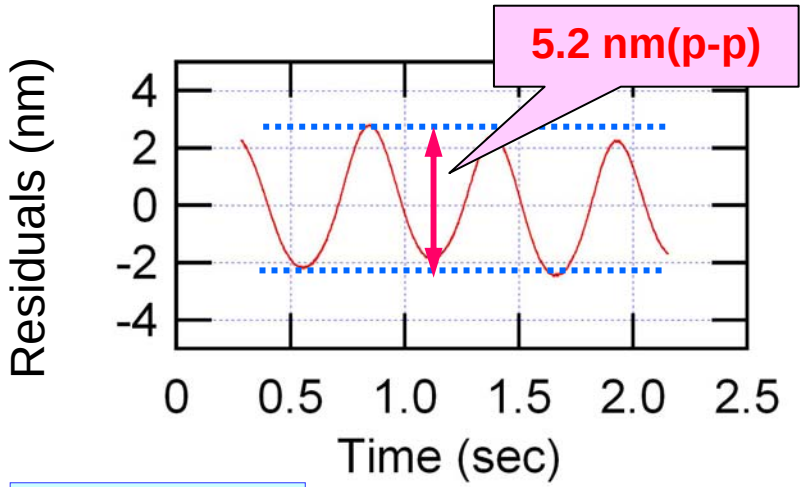
85 mm (W) x 95 mm (D) x 26 mm (H)

Signal processing diagram

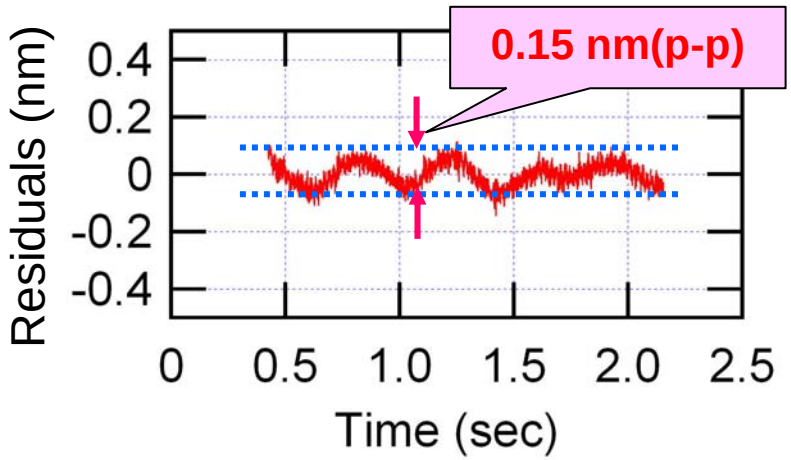


Result of correction

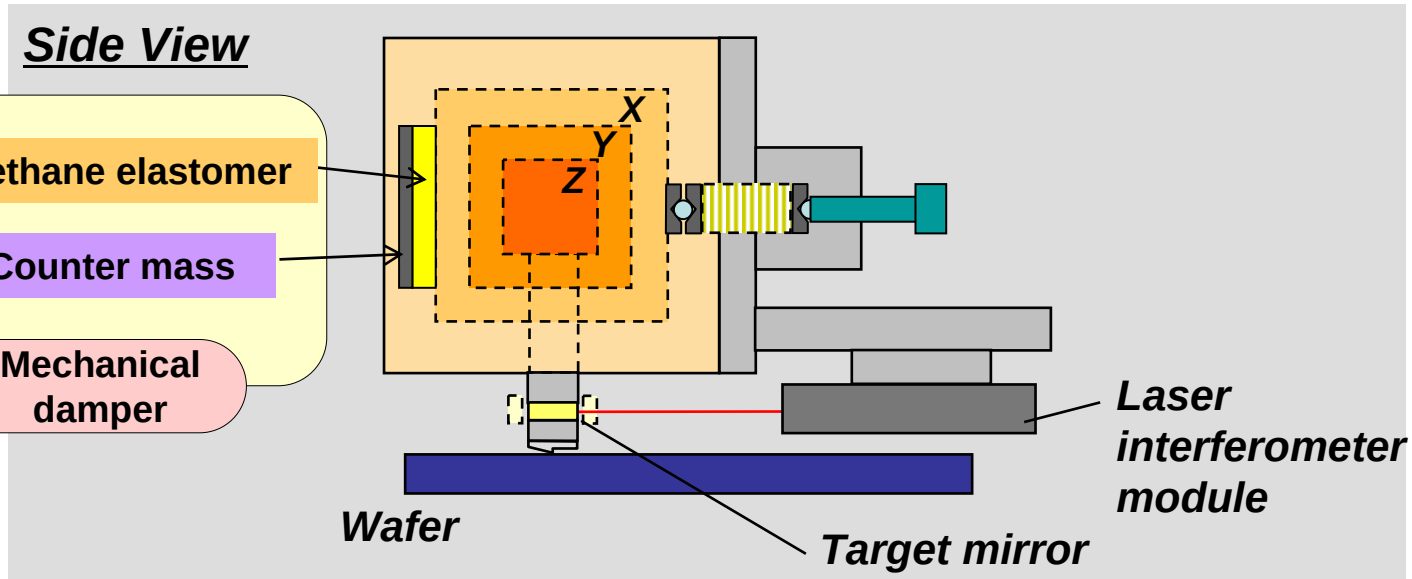


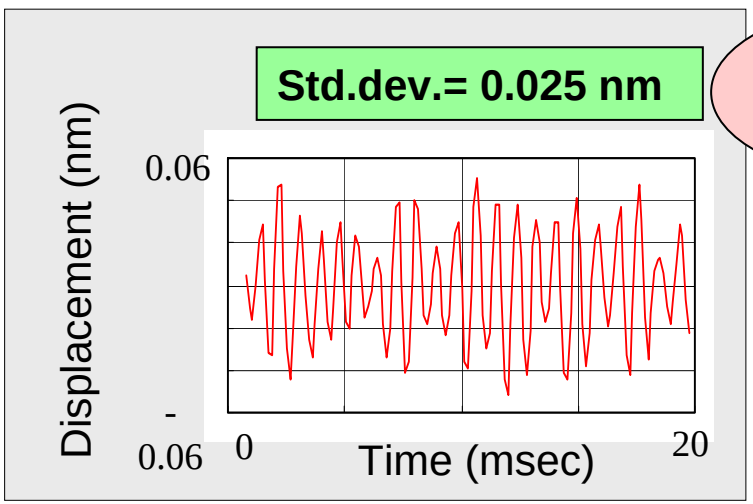


Correction parameter

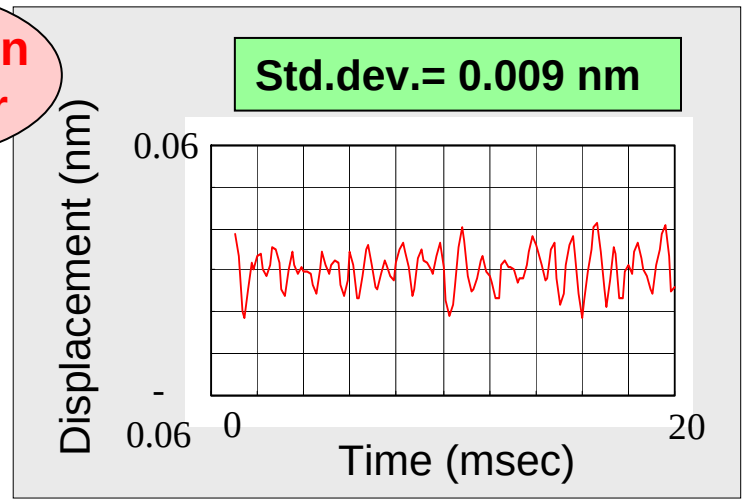


Reduction of mechanical vibration



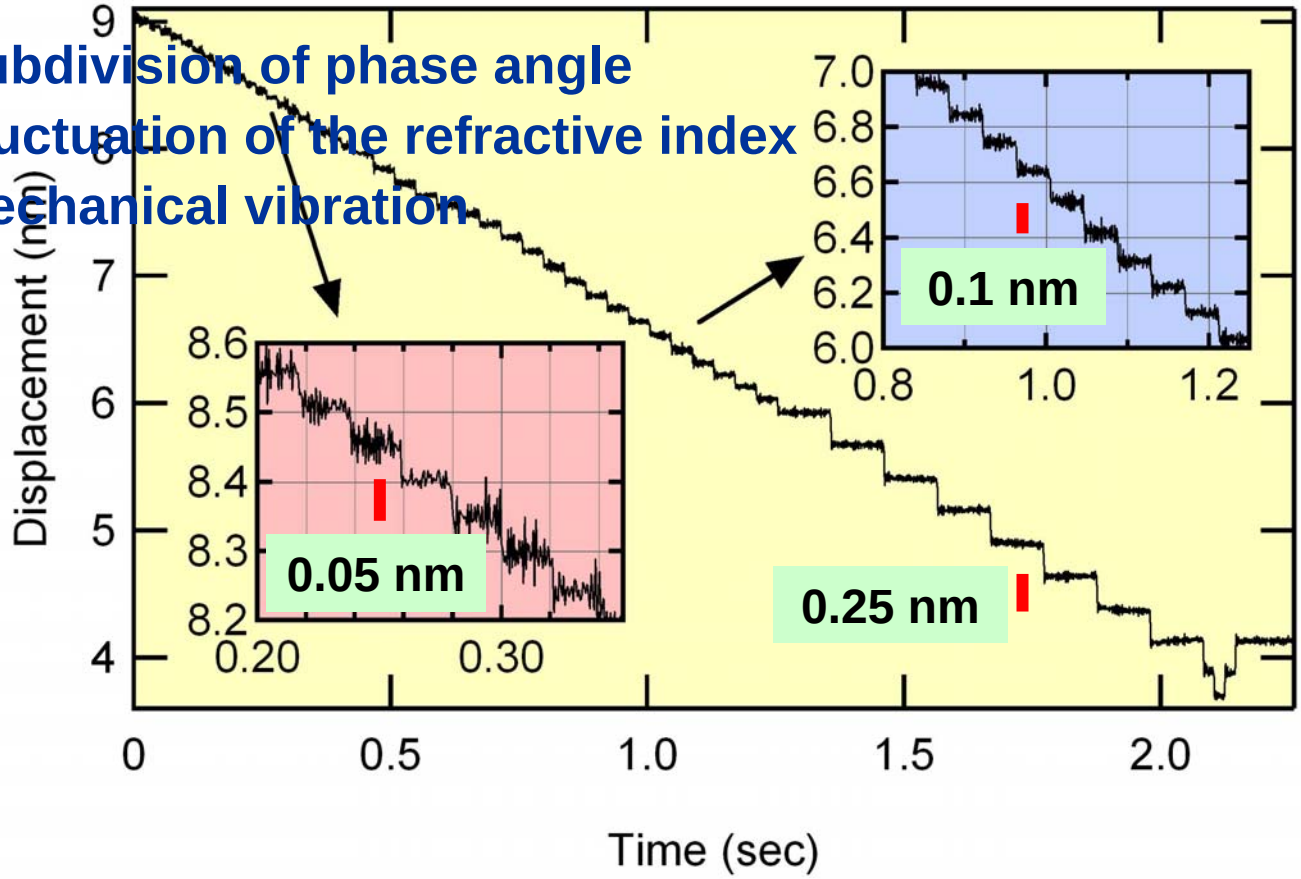


Installation of damper



Resolution

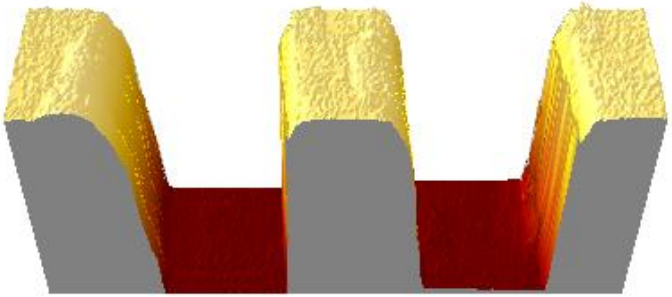
- Subdivision of phase angle
- Fluctuation of the refractive index
- Mechanical vibration



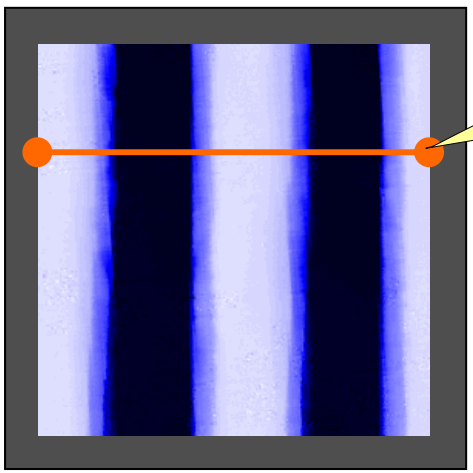
0.05 nm-steps are recognized.

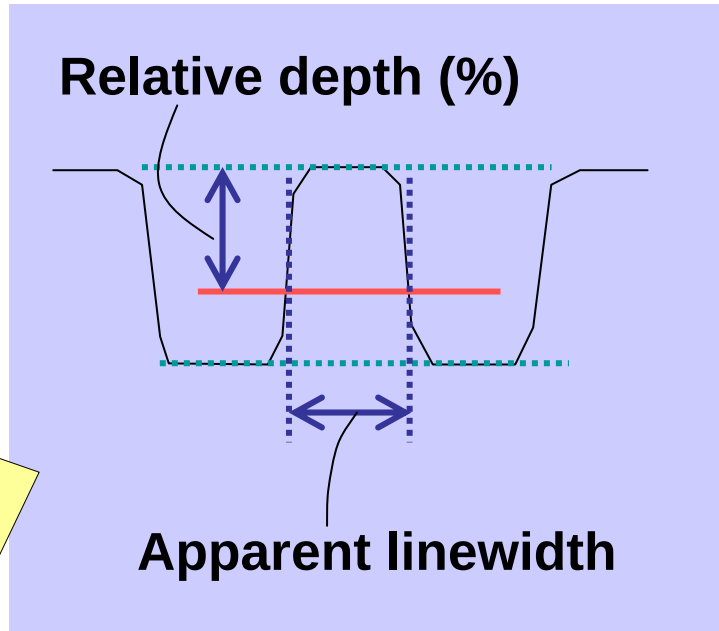
Measurement of apparent linewidth

- Scanning is servo-controlled
- Three-dimensional coordinates



240 nm pitch grating



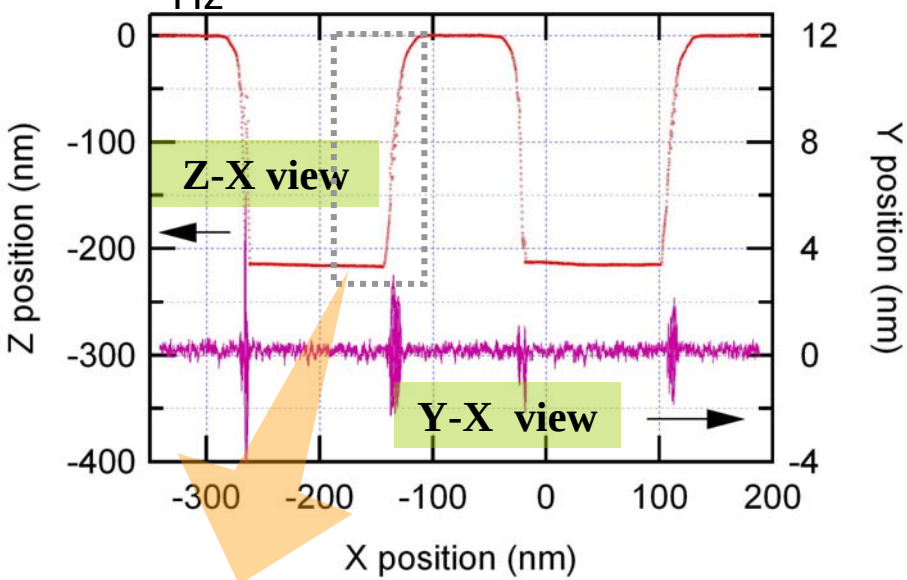


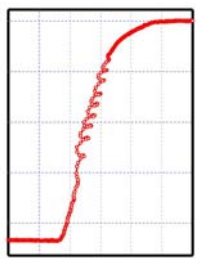
Repeatedly scanned at the same position

Cross-sectional profiles

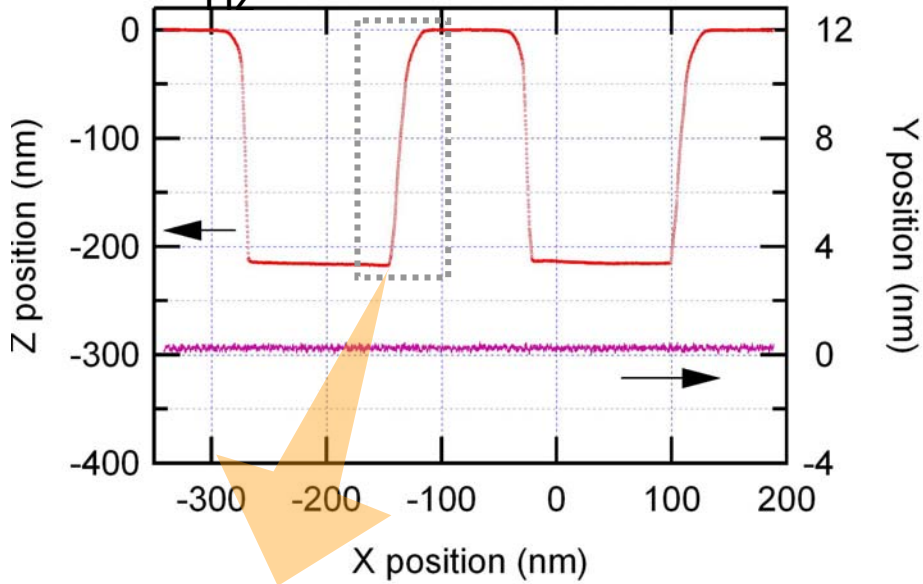
Optimization of servo

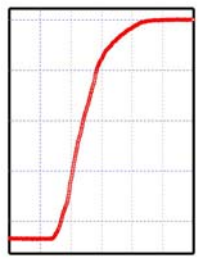
I gain=0.025
P gain=0.010
Scanning rate：0.25 Hz





I gain=0.012
P gain=0.007
Scanning rate：0.13 Hz



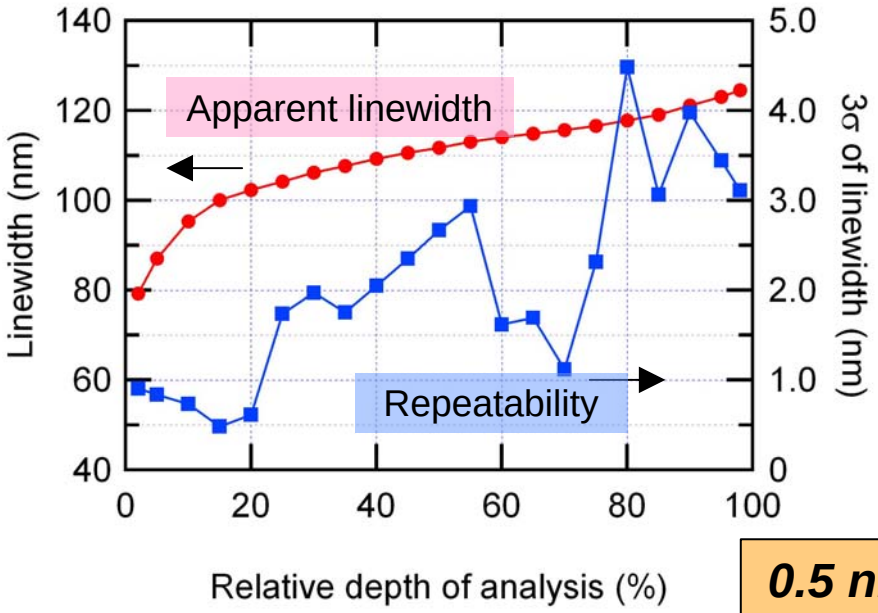


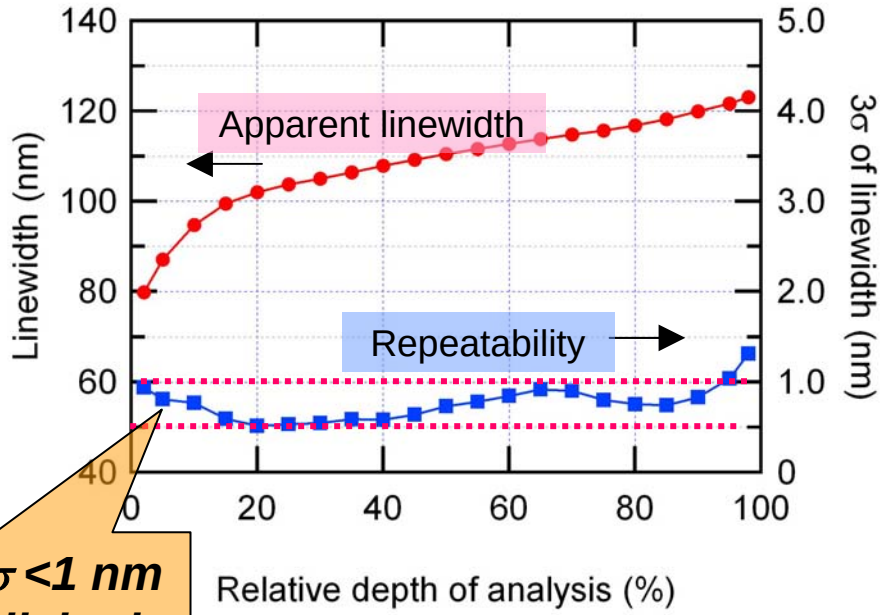
Repeatability of apparent linewidth

I gain=0.025
P gain=0.010
Scanning rate：0.25 Hz

Optimization of servo

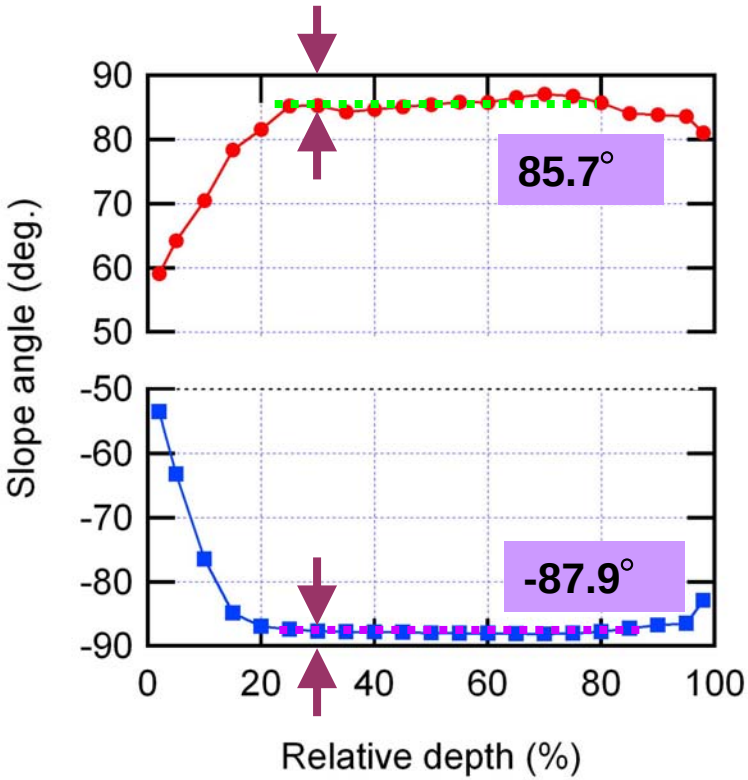
I gain=0.012
P gain=0.007
Scanning rate：0.13 Hz

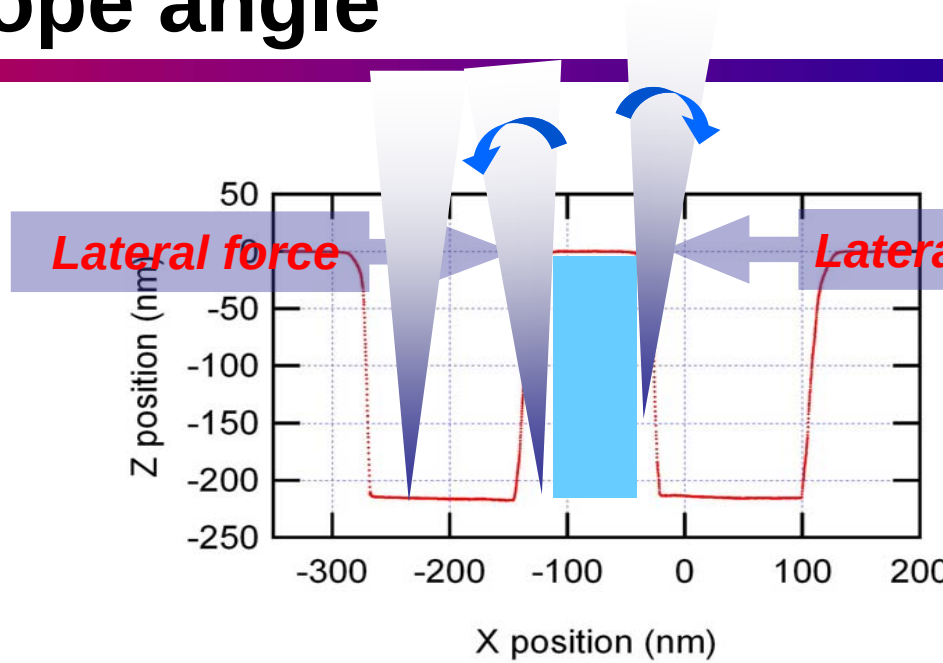


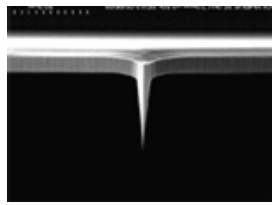


0.5 nm < 3σ <1 nm was established

Slope angle



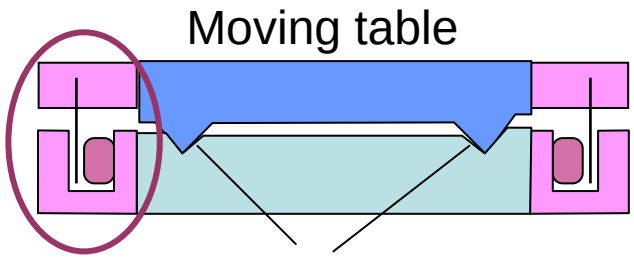




Deformation of both tip and lever is suggested.

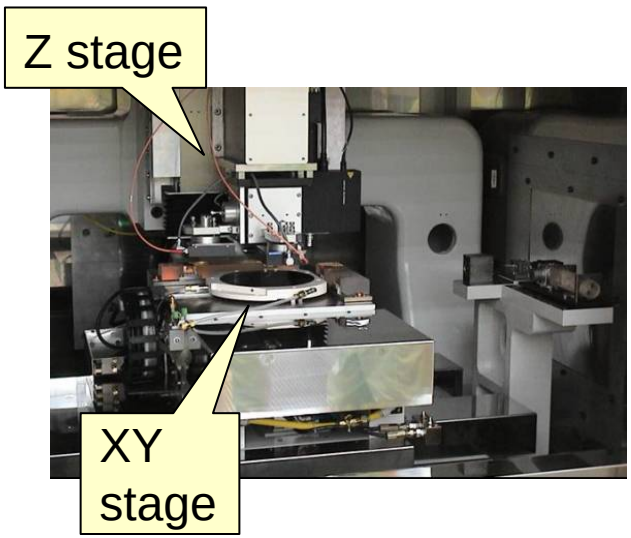
The sum of remaining 90° = 6.4° < **Full cone angle of tip = 12°**

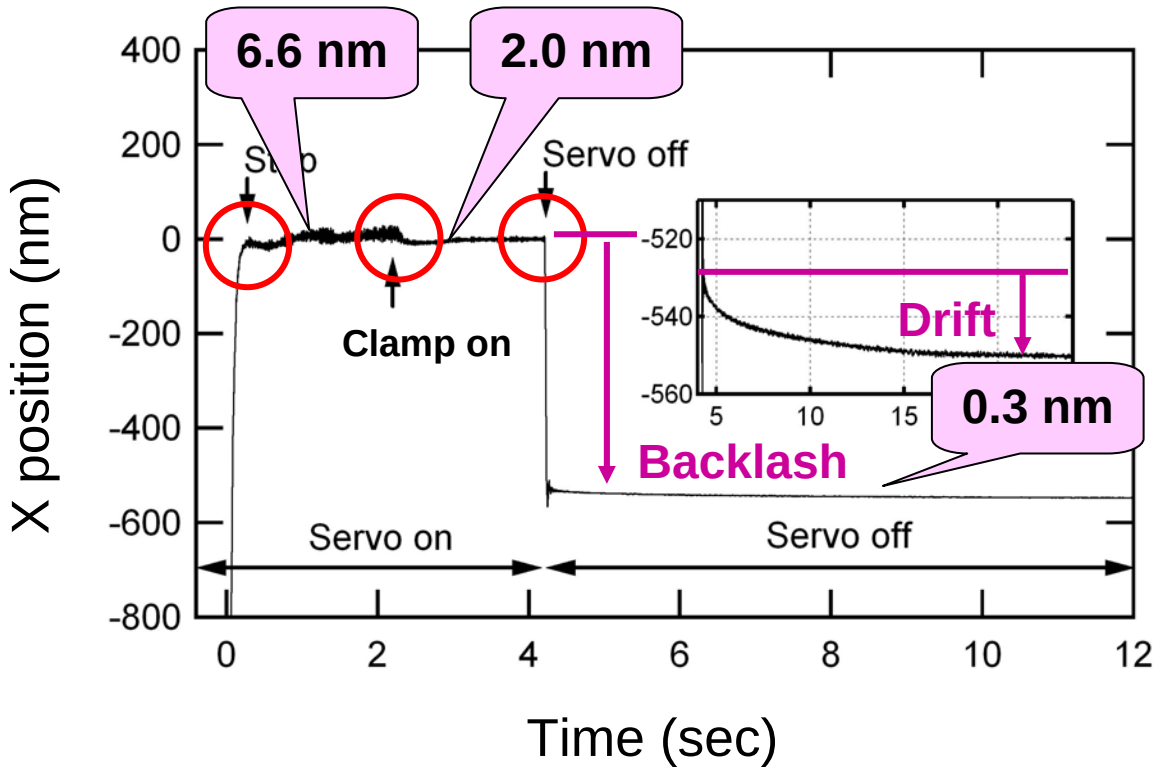
Backlash and drift at a stop



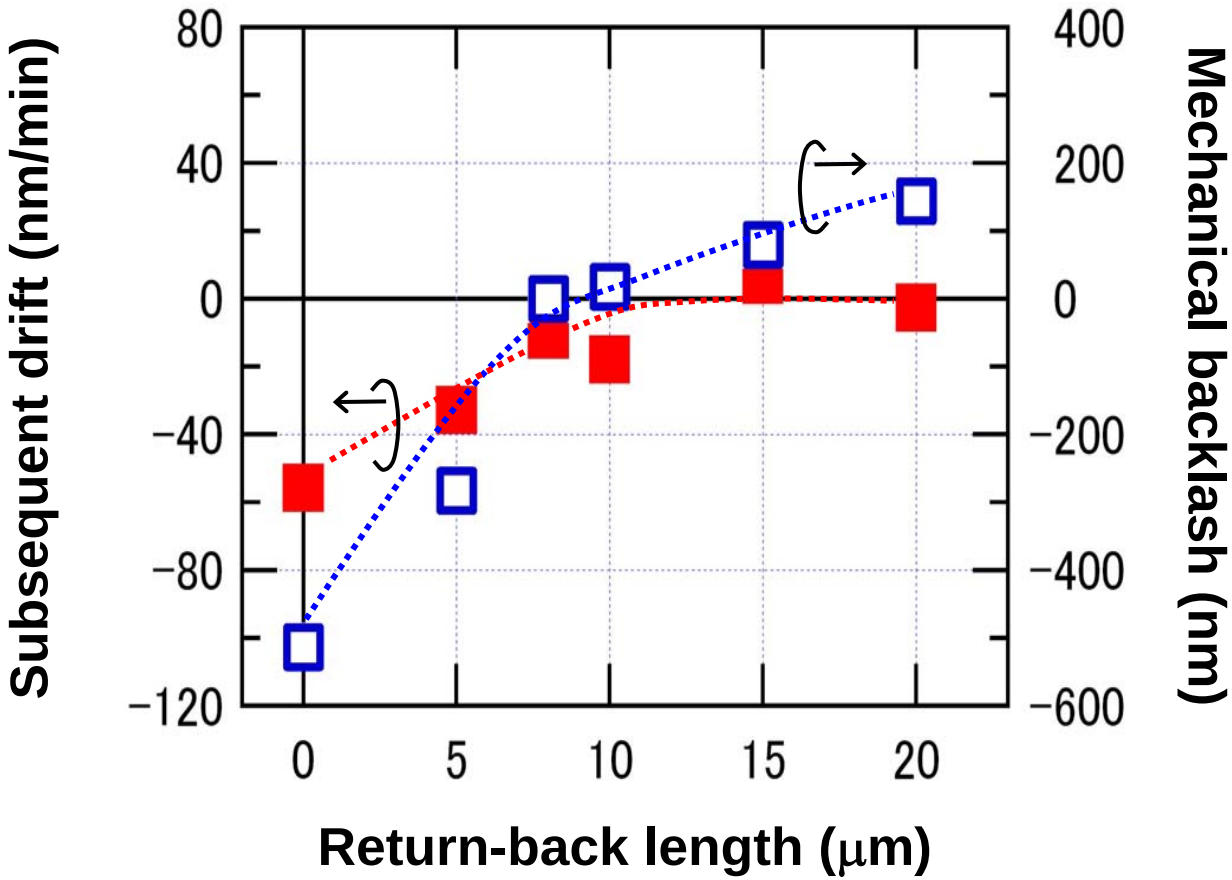
Clamping and cut off of servo control are necessary in AFM measurements.

< Backlash and drift caused by stress relief >





Optimum condition : backlash / drift



Summary

High-resolution interferometer system was constructed and installed in a metrological AFM.

Linearity has been improved better than 0.15 nm(p-p) by DSP based, cyclic error correction system.

Resolution better than 0.05 nm for the system of the laser interferometer and 3D fine-motion scanner was demonstrated.

Repeatability of apparent linewidth reached 0.5-1.0 nm(3σ).

***This work was supported by NEDO.**

Future work

Achieving of the measurement accuracy of 0.3-0.5 nm(3σ) for dynamic repeatability.

Investigating the influence of probe deformation on the measurement uncertainty.