APS Metrology Laboratory – Update on Instrumentation and Recent Activities

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Experimental Facilities Division

Advanced Photon Source

Office of Science
U.S. Department of Energy

TWG Meeting

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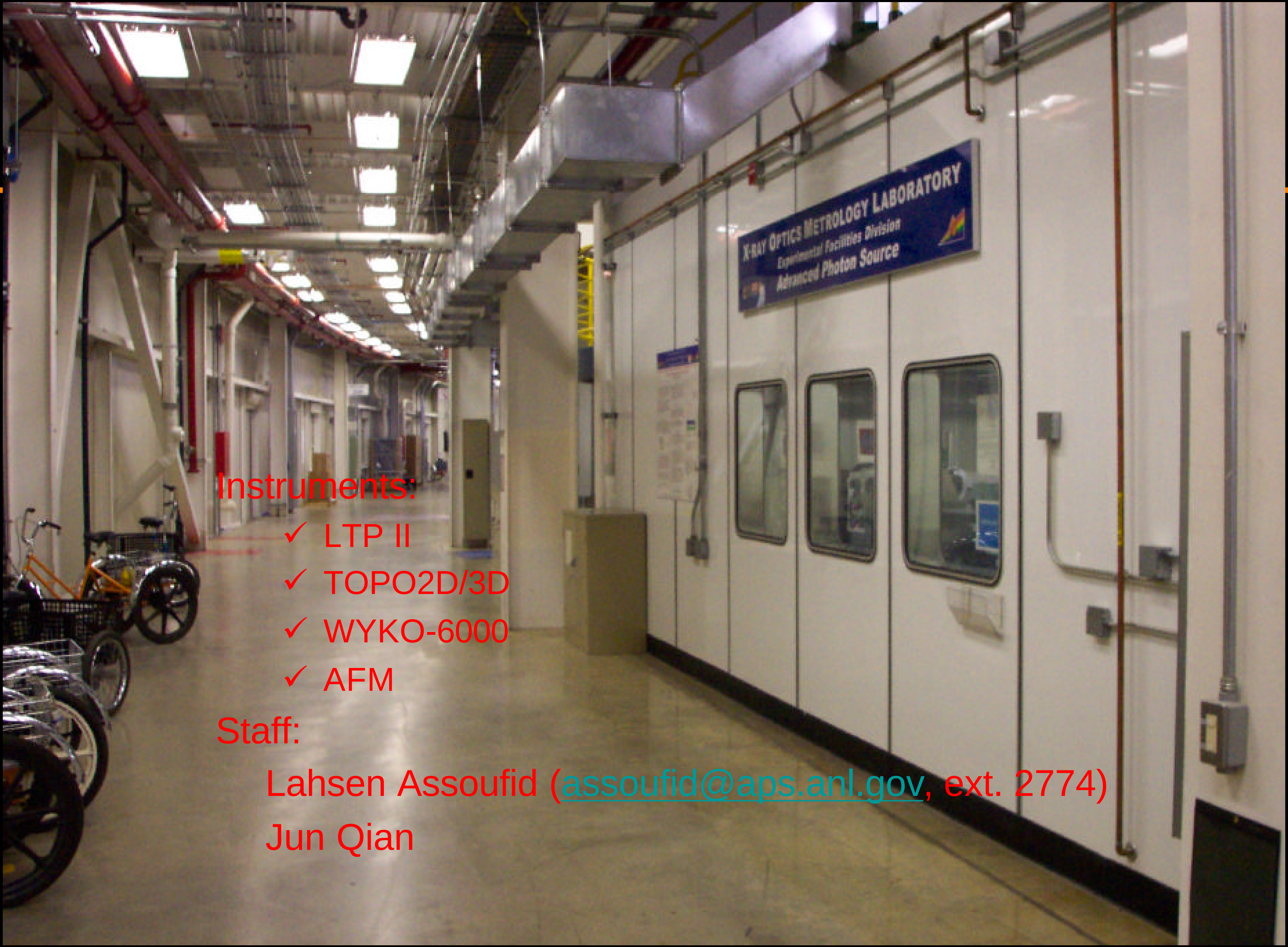
Outline

- Update on mirrors and their measurements
- Overview of instrumentation and upgrades
- Stitching program and future plans
- Closing remarks



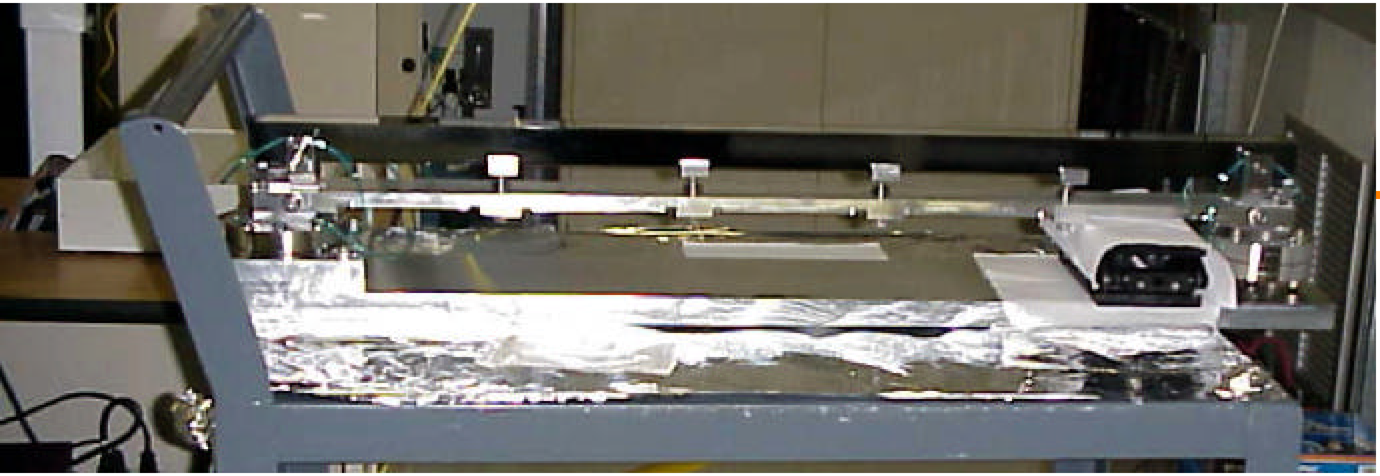
Instruments:

- ✓ LTP II
- ✓ TOPO2D/3D
- ✓ WYKO-6000
- ✓ AFM

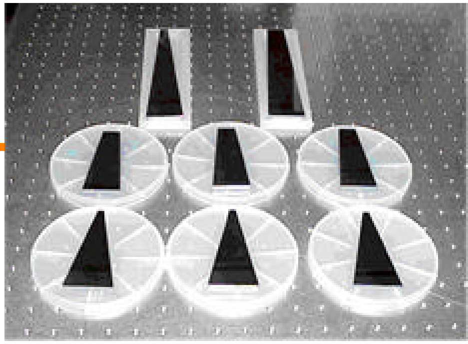
Staff:

Lahsen Assoufid (assoufid@aps.anl.gov, ext. 2774)
Jun Qian

Example of mirrors, substrates and benders evaluated at the APS metrology laboratory

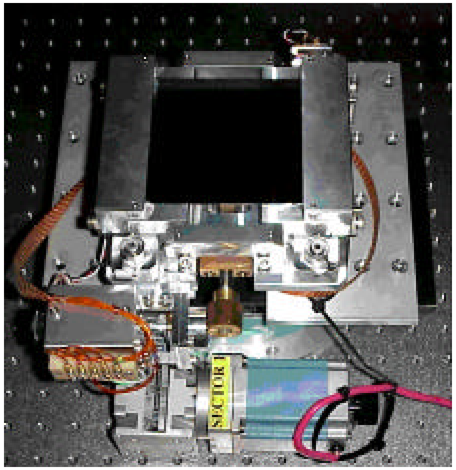


BioCARS mirror-bender (R. Pahl)



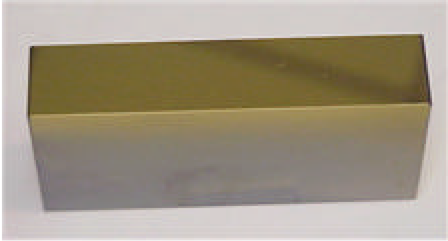
GSECARS K-B substrates
(Owner: P. Eng)

Bimorph mirrors (HP, D. Hausermann

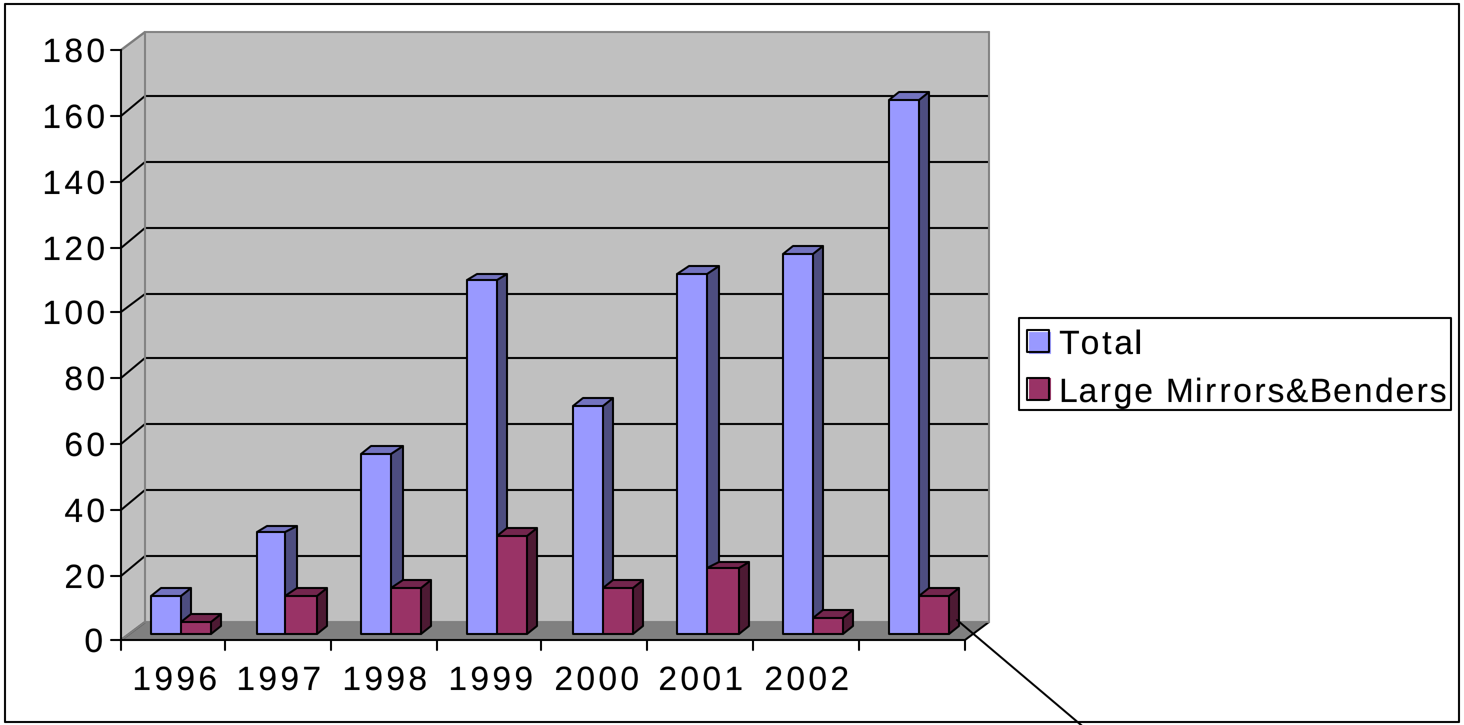


XOR mono-bender (Owner: Suresh)

UNI, K-B optics (Owner: G. Ice)



Measurement requests over the years



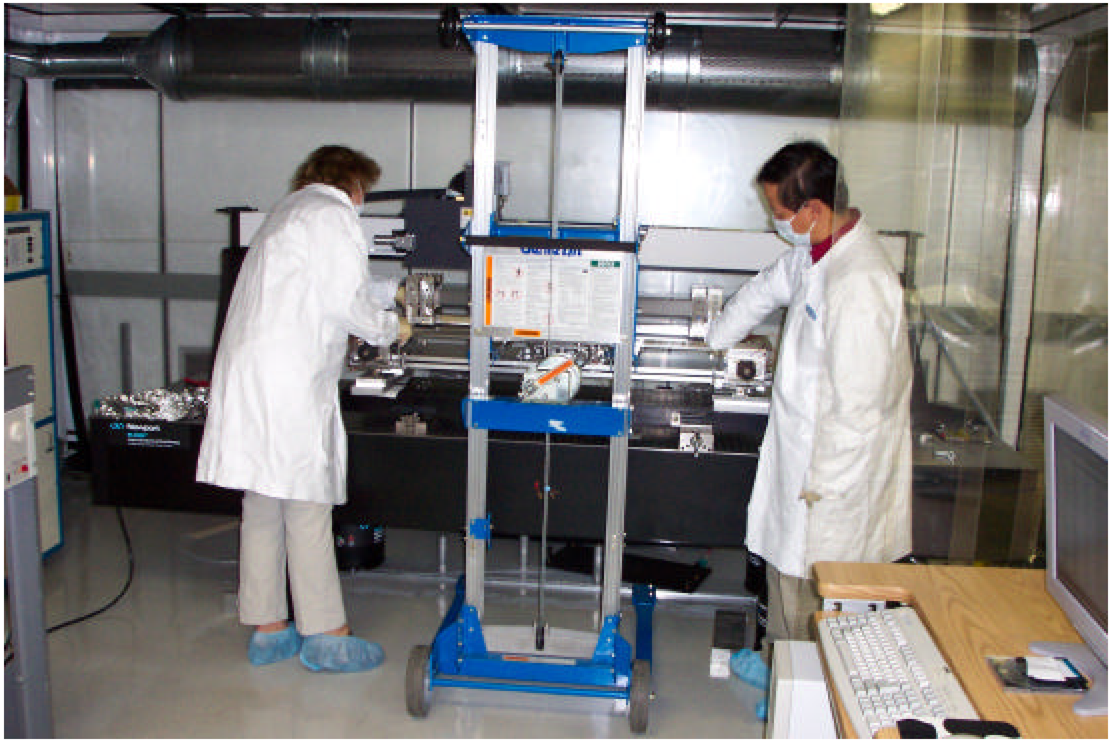
Includes new and used

Large: 0.5 - 1.2 m
Small: =300 mm

Mirror surface quality

Parameter	**Large Mirrors** **(0.5 - 1.2 m)**		**Small Optics** **(=300 mm)**	
	Best	*Typical*	*Best*	*Typical*
Slope error (µrad rms)	0.43	2.0 - 2.5	0.3	1.0 - 2.0
Roughness (Å rms)	1.4	1.5 - 2.5	0.5	1.5 - 2.5

APS LTP II:
Installation of a new mirror tip/tilt table

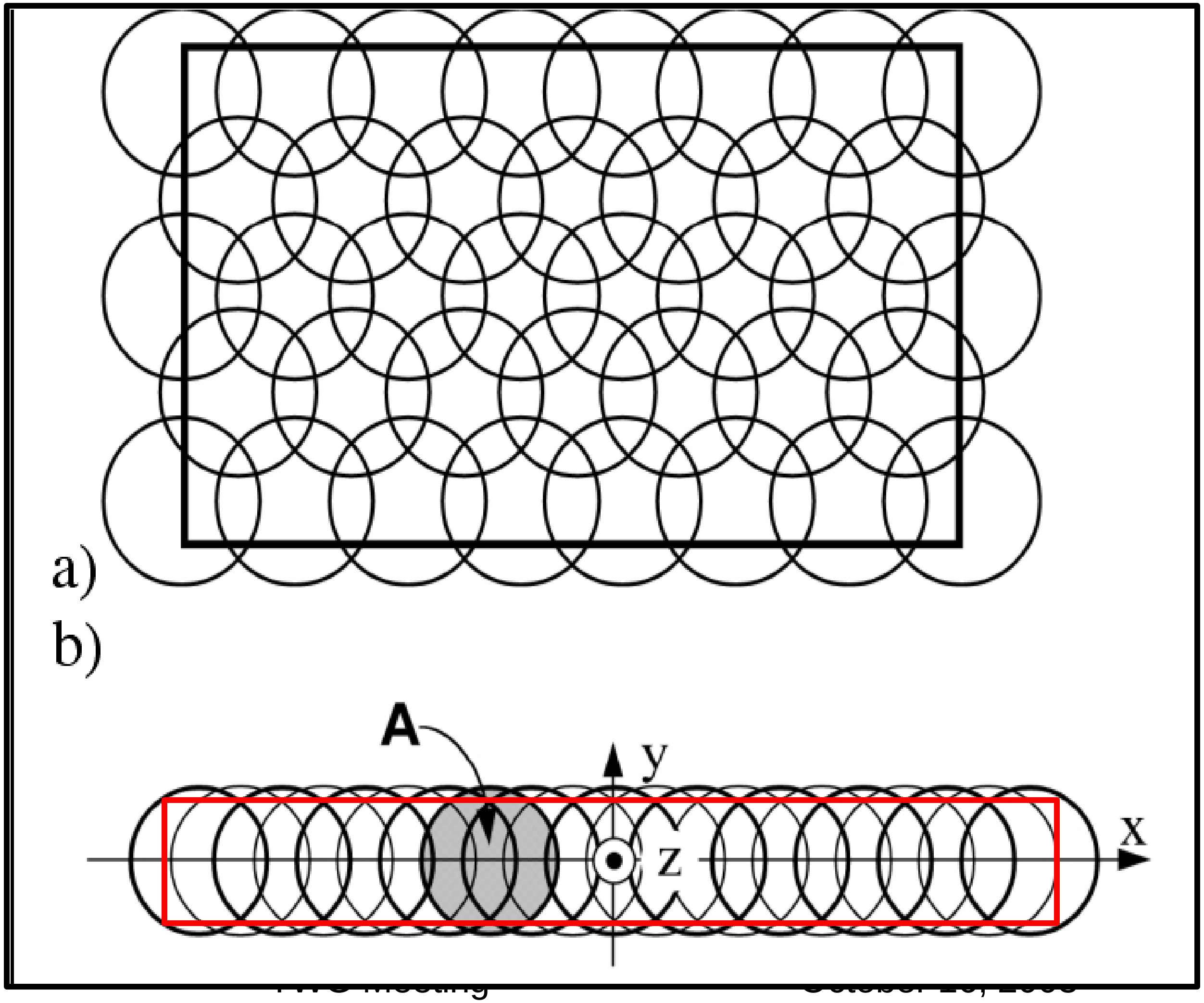


Evaluation of a IMCA-CAT mirror-bender assembly using the newly-installed tip/tilt table.

- Can handle larger and heavy mirror assemblies
- More stable and, therefore, safer
- Provides large height clearance.
- Can be motorized for remote control operation and automatic multiple scans.

Development of a stitching interferometry system for evaluating large x-ray mirrors and substrates

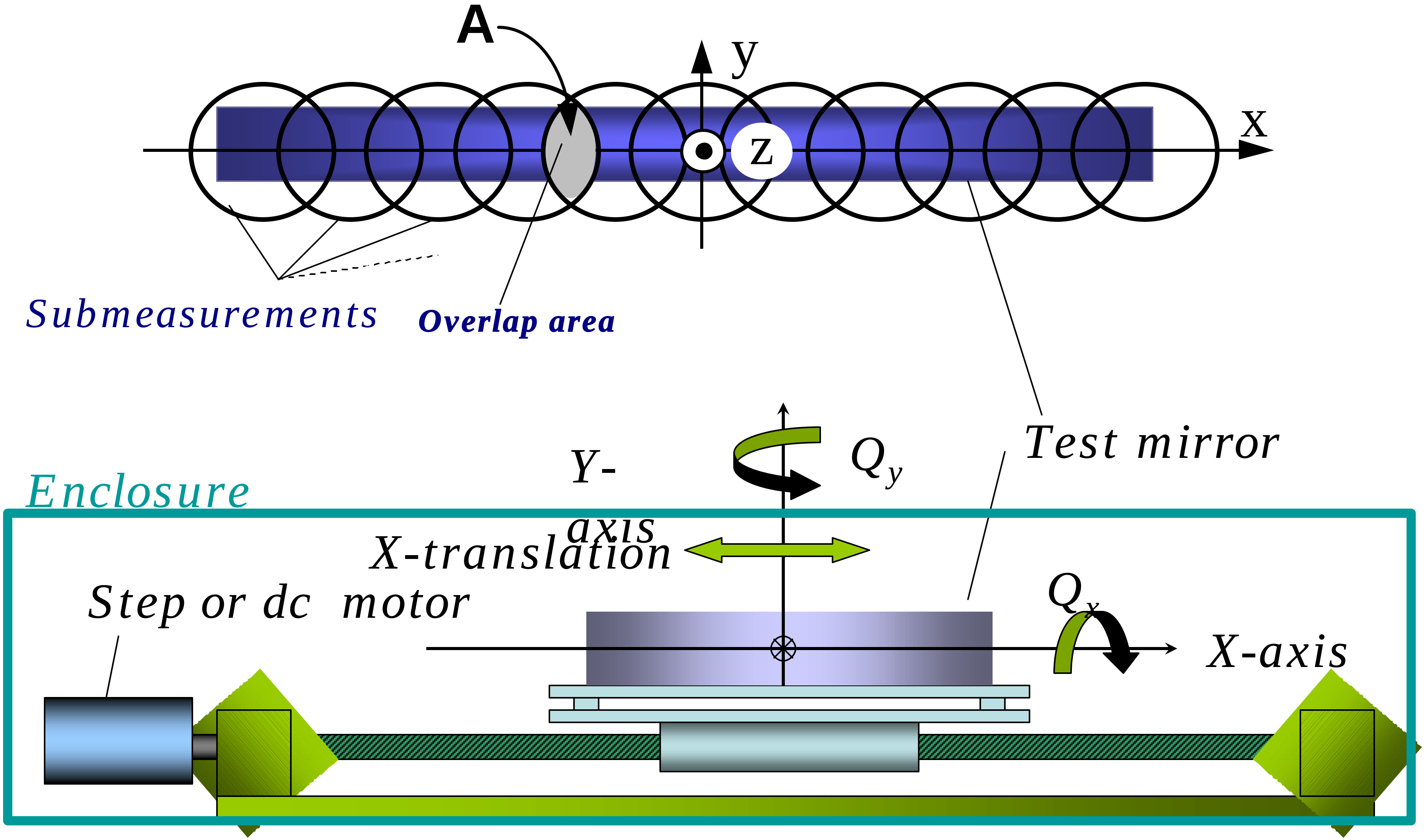
- Basic principle



Motivations for stitching

- Stitching can cover a range of spatial frequency wider than with the current LTP systems.
- High resolution measurement can be obtained provided that the subaperture measurements are accurate and free from errors.
- 3-D surface profile of the a full mirror aperture can be obtained, while the LTP only provides a single trace profile.
- A 3-D surface profile can allow one to chose the best area on the mirror surface, which is particularly useful for ID beams.
- The data can be useful for simulation purposes.
- Measurements can be automated.
- Complementary to LTP (Independent measurement)

Principal of stitching



Submeasurements

Overlap area

Test mirror

Enclosure

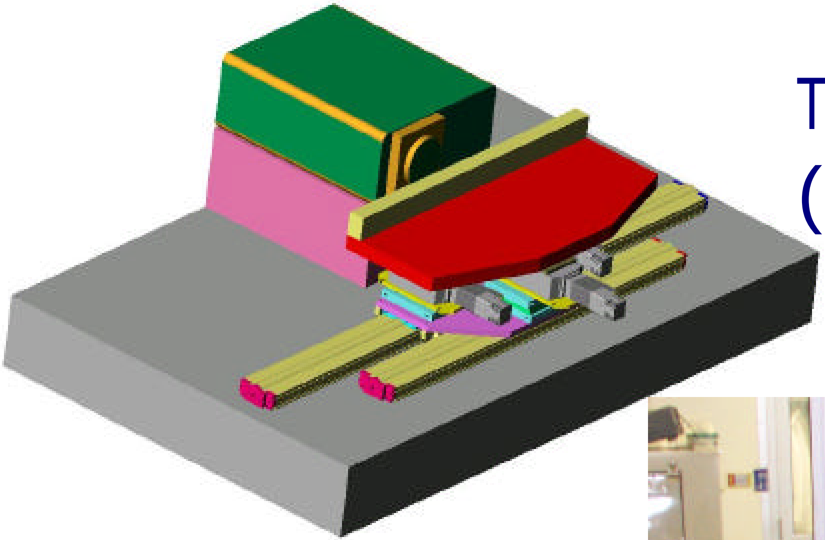
Y-axis

X-translation

Step or dc motor

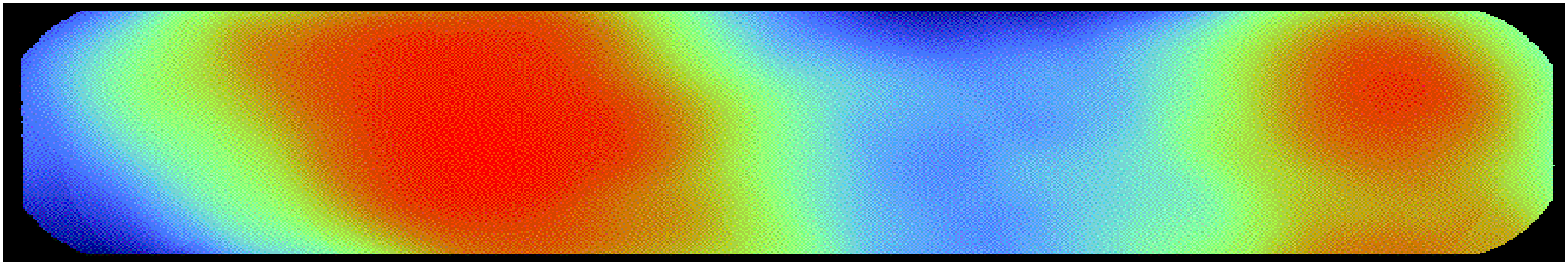
X-axis

The current stitching system (Still under construction)

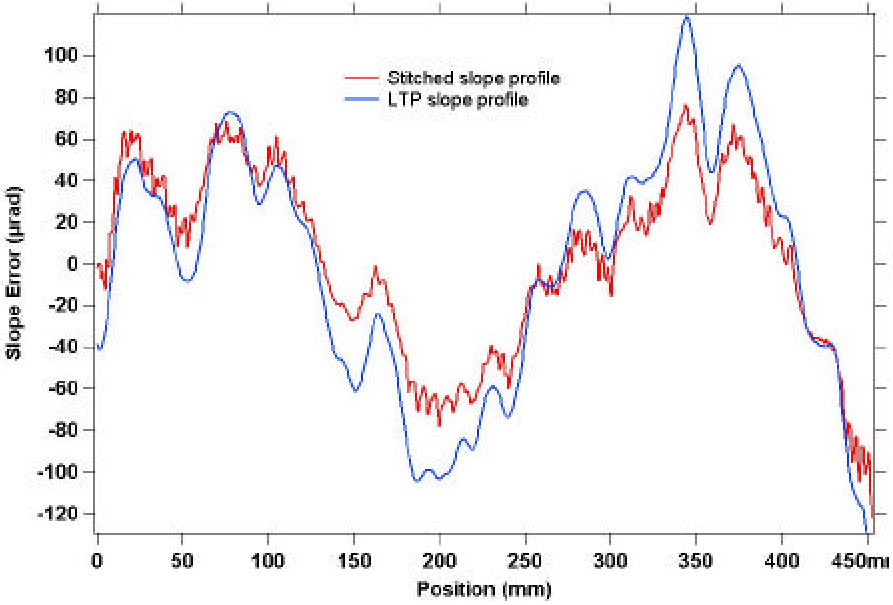


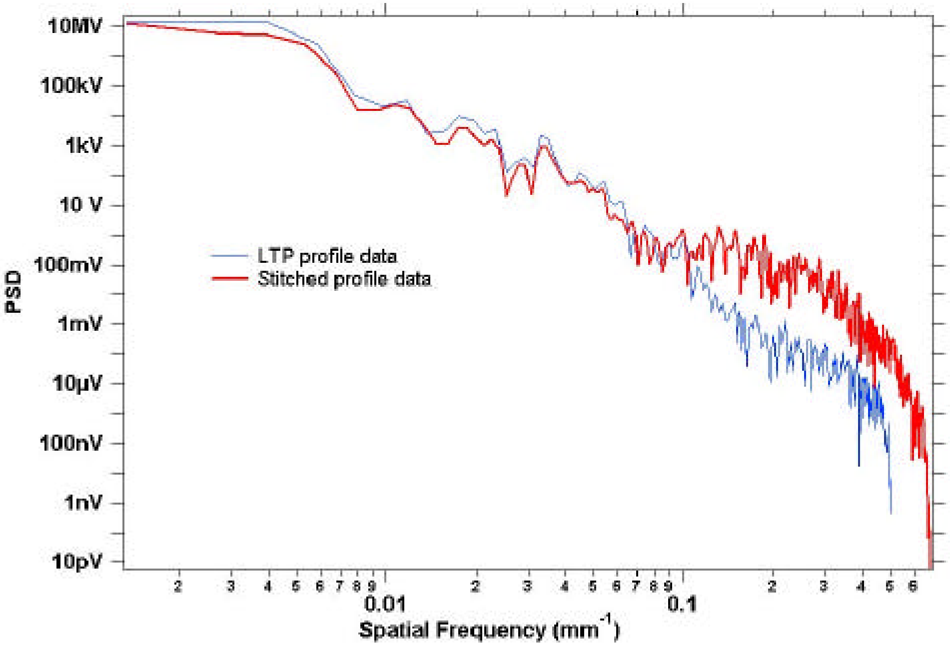
Application to a 460-mm-long float glass substrate

Stitched surface contour profile

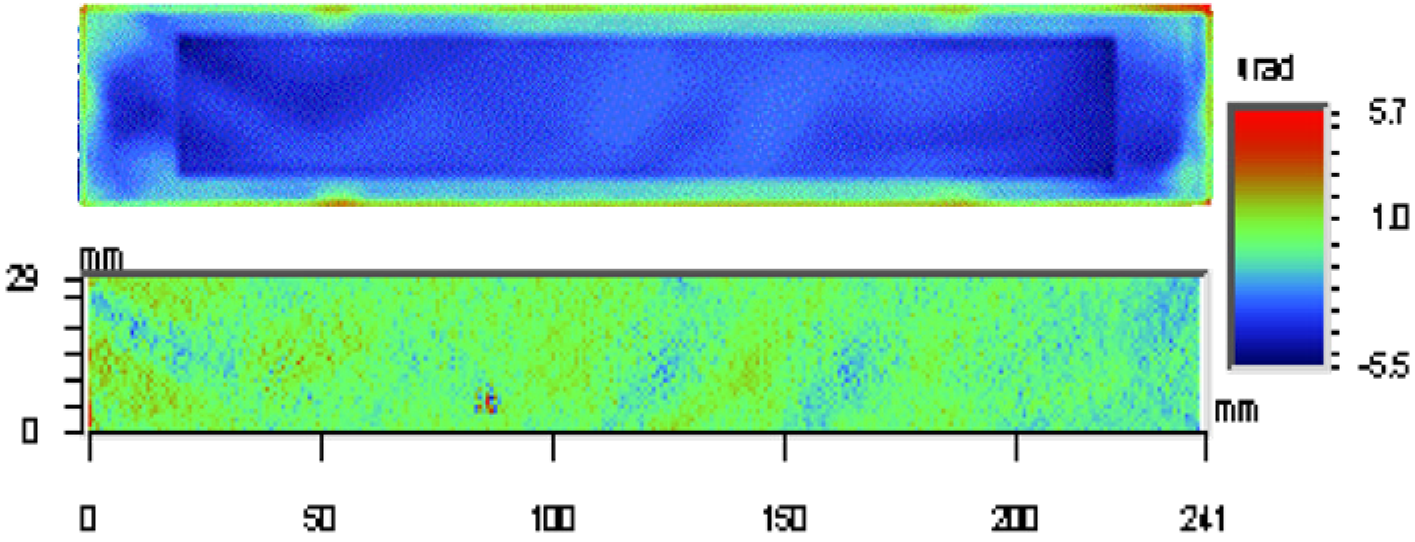


Application to a 460-mm-long float glass substrate - Comparison with the LTP





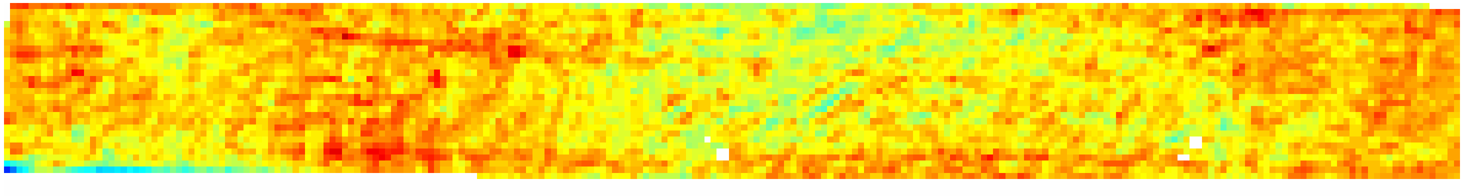
Application to a 300-mm superpolished Si flat substrate



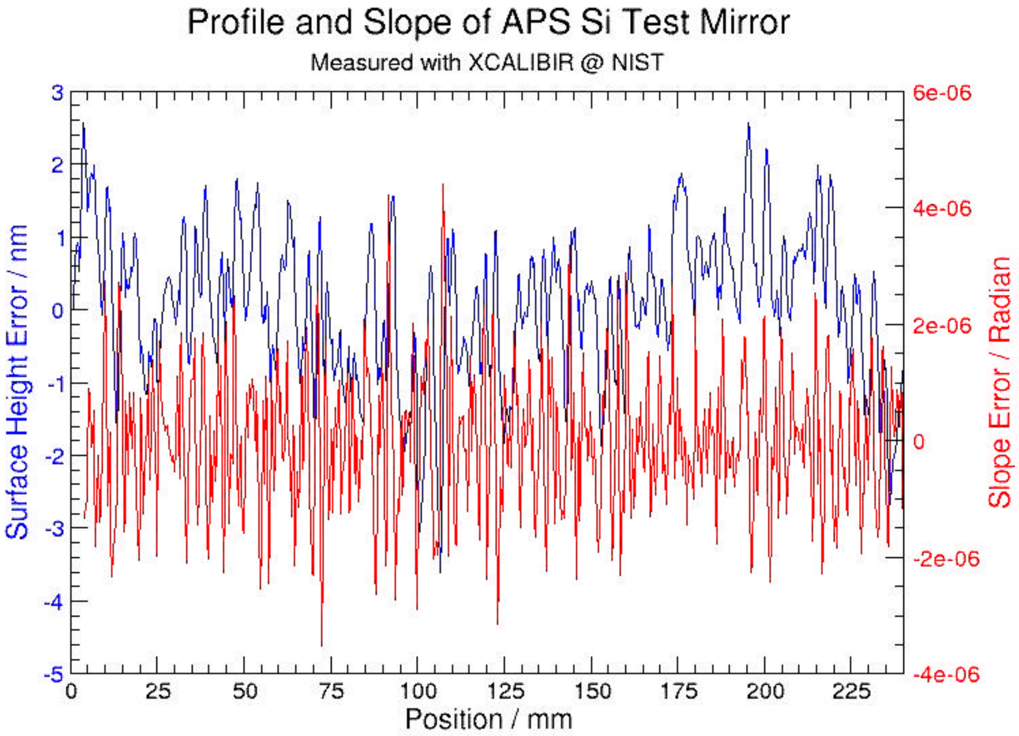
Top: Height contour profile - Bottom: Residual slope contour profile over the useful area (inner rectangle in a) => ***No evidence of overlap error observed.***

	STITCHING	**LTP**	**ASML**
rms slope error (µrad)	0.64	0.66	0.62

A measurement of the 300 mm superpolished Si flat with the NIST XCALIBIR interferometer



APS mirror figure error



Profile and Slope of APS Si Test Mirror

Measured with XCALIBIR @ NIST

- Good signal-to-noise ratio with sub-nm height resolution.
- High frequency noise ~0.2 nm (2 x silicon atom diameter).
- Source of low frequency component not yet understood. Could be vibration related noise.

Courtesy U. Giesmann, NIST

Stitching challenges

- Obtain accurate and error-free subaperture measurements is the main challenge.
- Interferometer-related errors:
  - ✓ system aberrations and PZT phase shifter nonlinearities:
    => Calibration
  - ✓ Noise:
    => Averaging

- Environment-related errors:
  - ✓ Air turbulence:
    => Small airpath/cavity, averaging
  - ✓ Mechanical stability/vibration:
    => Better design, averaging
    => Real time interferometry
  - ✓ Temperature stability

Interferometer calibration

- Interferometers always measure the sum of error in reference surface and test part surface.

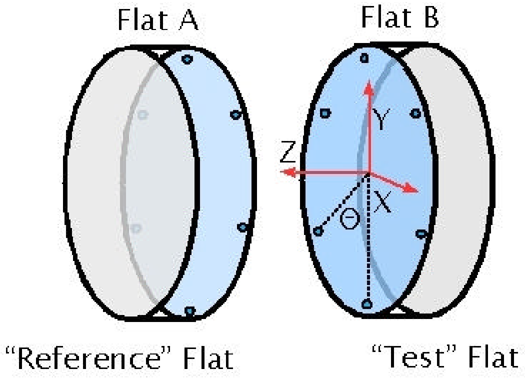
- Methods for “error separation” have been devised during the past 20 years.

3-flat test:

$$M_1(x,y) = A(x,y) + B(-x,y)$$
$$M_2(x,y) = A(x,y) + C(-x,y)$$
$$M_3(x,y) = B(x,y) + C(-x,y)$$

(See for example: Chiayu Ai and J.C. Wyant, Appl. Opt. 32, 498-4705 (1993).)

N-position test: N-1 additional measurements are made with flat C rotated by 360°/N increments. The topography of all surfaces can then be determined **with the exception of a component with N-fold symmetry.**

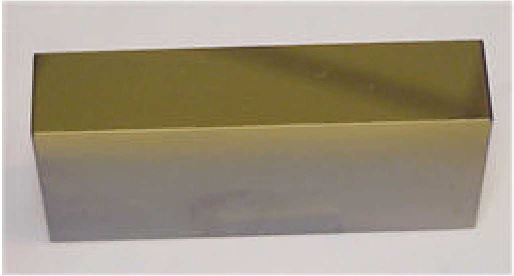


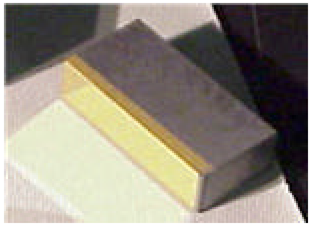
3-Flat N-position test:
R. E. Parks, L. Shao, and C. J. Evans, Appl. Opt. **37**, 5951-5956 (1998)

3-Flat rotational shearing test:
K. R. Freischlad,
Appl. Opt. **40**, 1637-1648 (2001)

Lateral shearing test:
C. Elstner,
Appl. Opt. **39**, 5353-5359 (2000)

Development of tools and methods for metrology of elliptical K-B mirrors



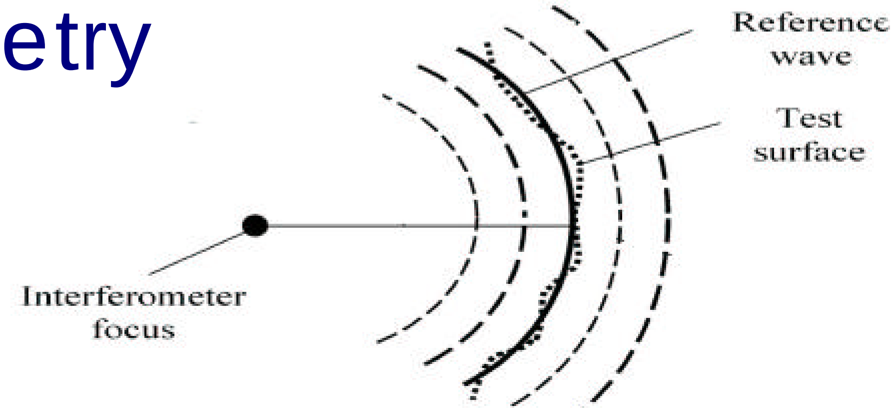


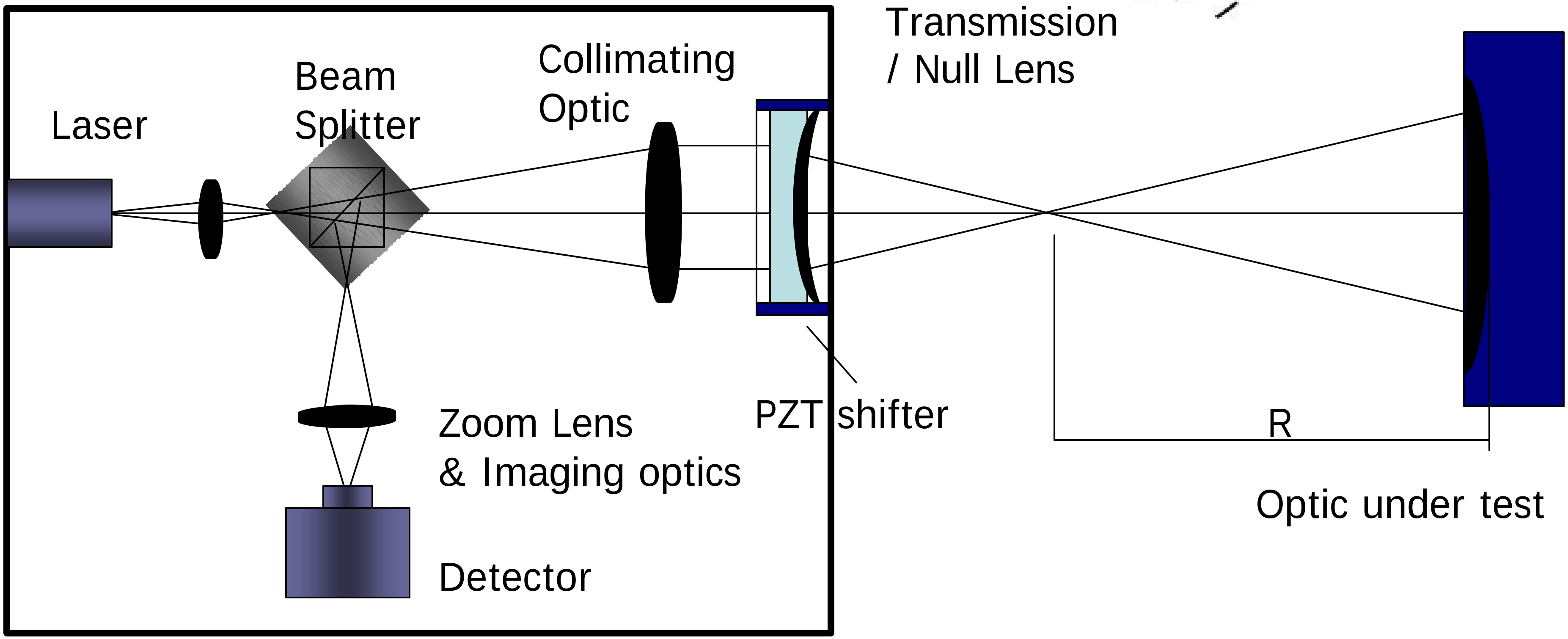
- Diffraction-limited K-B mirrors are in demand (G. Ice and J. Tischler)
- K-B mirror substrates with 0.2 µrad rms slope error are expected to be delivered soon (G. Ice and A. Khounsary)

- **Possible Techniques:**
  - ✓ PMI + null optics
  - ✓ Microstitching interferometry
  - ✓ High resolution small trace laser profiler
  - ✓ Large-Area Curvature Sensor Method

Metrology of K-B mirrors with Phase Measuring Interferometry

- ➢Requires a non standard transmission optic to generate the desired test wavefront.





Laser

Beam Splitter

Collimating Optic

Transmission / Null Lens

Zoom Lens & Imaging optics

PZT shifter

R

Detector

Optic under test

Metrology of K-B mirrors: Microstitching Interferometry

Needs:

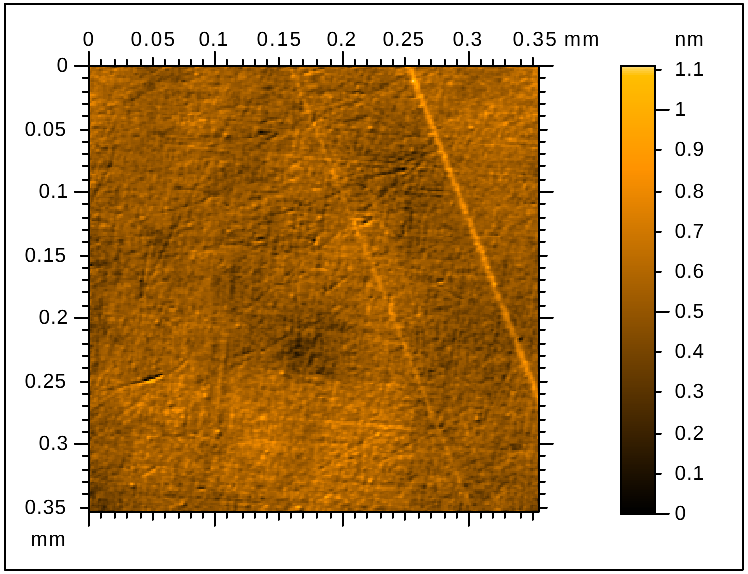
- ✓ A high resolution interferometer
- ✓ A high resolution positioning system
- ✓ A stitching software

A possible interferometer for microstitching + TOPO2D/3D replacement?

The Talysurf CCI 3000
fromTaylor-Hobson

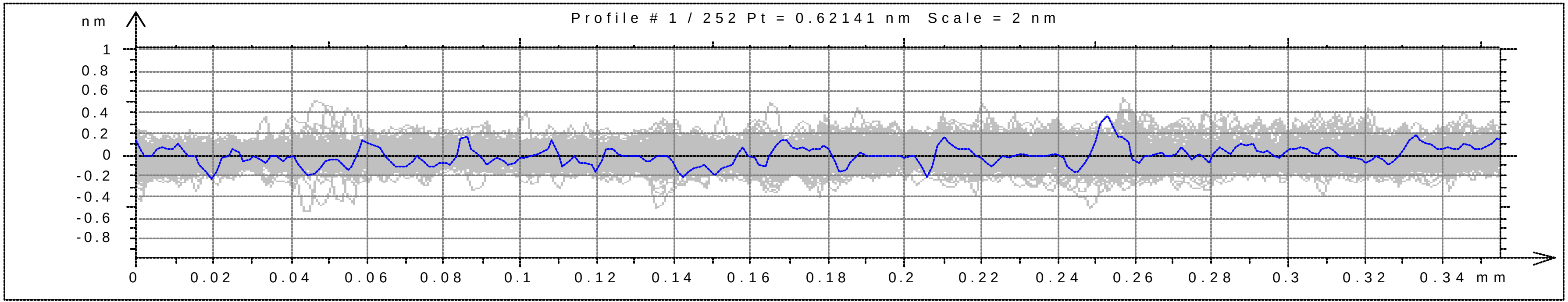
- Broadband interferometer
- Controlled bandwidth light source
- Highly repeatable scanning transducer
- Resolution: 10pm (0. 1Å)
- Repeatability: 0.03 Å rms
- Measures supersmooth and rough surfaces.

Example of measurement of a polished Si sample with a Talysurf CCI 3000

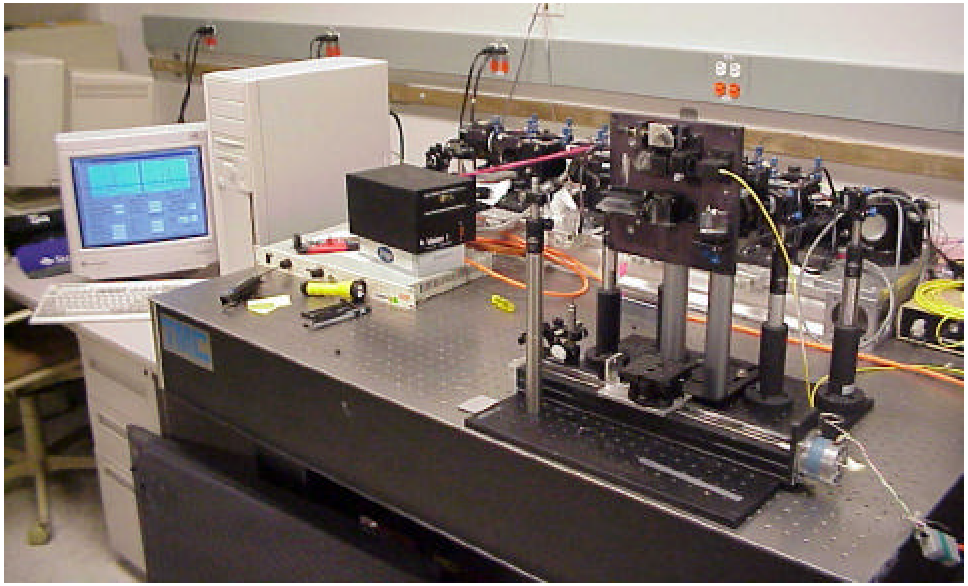


```
   Sa     = 0.07072 nm
            Sa: Arithmetic Mean Deviation of the
Surface.
   Sq     = 0.093034 nm
            Sq: Root-Mean-Square (RMS) Deviation
of the Surface.
   St     = 1.1102 nm
            St: total height of the surface.
```

```
  Pa     = 0.067092 nm              +/-   0.0067299 nm
           Min: 0.047443 nm / Max: 0.085997 nm
           Pa: Arithmetic Mean Deviation of the raw profile.
  Pq     = 0.088107 nm              +/-   0.0087987 nm
           Min: 0.061546 nm / Max: 0.11474 nm
           Pq: Root-Mean-Square (RMS) Deviation of the raw profile.
  Pt     = 0.55994 nm        +/-   0.097143 nm
           Min: 0.36683 nm / Max: 1.0148 nm
           Pt: Total Height of raw profile.
```



Metrology of K-B mirrors: Development of a high resolution small trace laser profiler



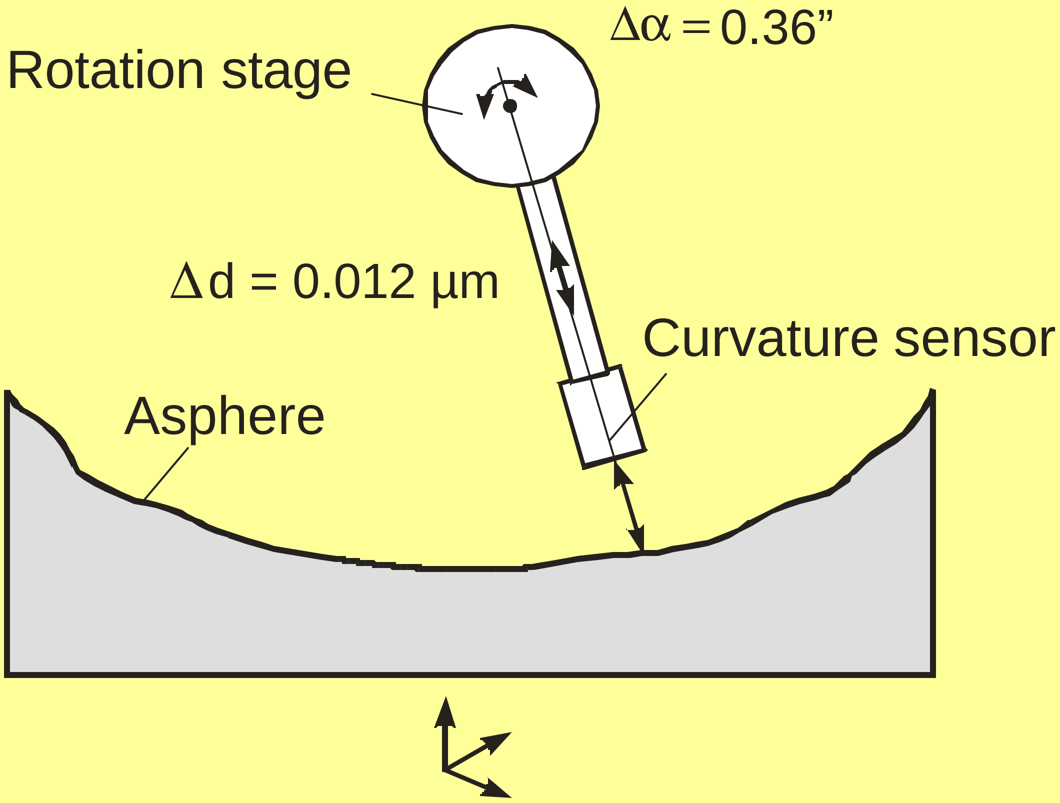
- Short trace length <300 mm
- Improvement of both mechanically- and environmentally-induced errors.
- A different sensor scheme should be developed

Large-Area Curvature Sensor Method

By Michael Shultz, and Ingolf Weingartner

Physikalisch-Technische Bundesanstalt

Braunschweig und Berlin



By Michael Shultz, and Ingolf Weingartner

Closing remarks

- The quality of mirrors continues to improve
- Instruments will be gradually upgraded
- Stitching interferometry is being developed for high resolution measurement of flats
- The stitching technique will be extended to measurement of elliptical K-B mirrors

- We appreciate any feedback and data sharing on actual beamline performance of your mirrors.
- We are open for collaboration on metrology measurements and instrumentation R&D.
- We welcome any suggestions that will help us to provide you with the best of services.

- Metrology measurements are free of charge for APS users.

Acknowledgments

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