High Speed Reflectometer for EUV Mask Blanks

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Abstract:

AIXUV GmbH and partners have developed a high speed Reflectometer for EUV mask blanks which is fully compliant with the SEMI-standard P38 for EUV-mask blank metrology.

The system has been installed in June 2004 at SCHOTT Lithotec AG.

It features high throughput, high lateral and spectral resolution, high reproducibility and low absolute uncertainty. Using AIXUV's EUV-LAMP and debris mitigation, low cost-of-ownership and high availability is expected. The spectral reflectance of up to 3 mask-blanks per hour can be measured with at least 20 spots each. The system is push button-controlled. Results are stored in CSV file format.

For a spot size of 0.1×1 mm^2, 2000 spectral channels of 1.6 pm bandwidth are recorded from 11.6 nm to 14.8 nm. The reflectance measurement is based on the comparison of the sample under test to two reference mirrors calibrated at the PTB radiometry laboratory at BESSY II. The three reflection spectra are recorded simultaneously.

For each spot more than 10^7 photons are accumulated in about 20 s, providing statistical reproducibility below 0.2 % RMS. The total uncertainty is below 0.5 % absolute.

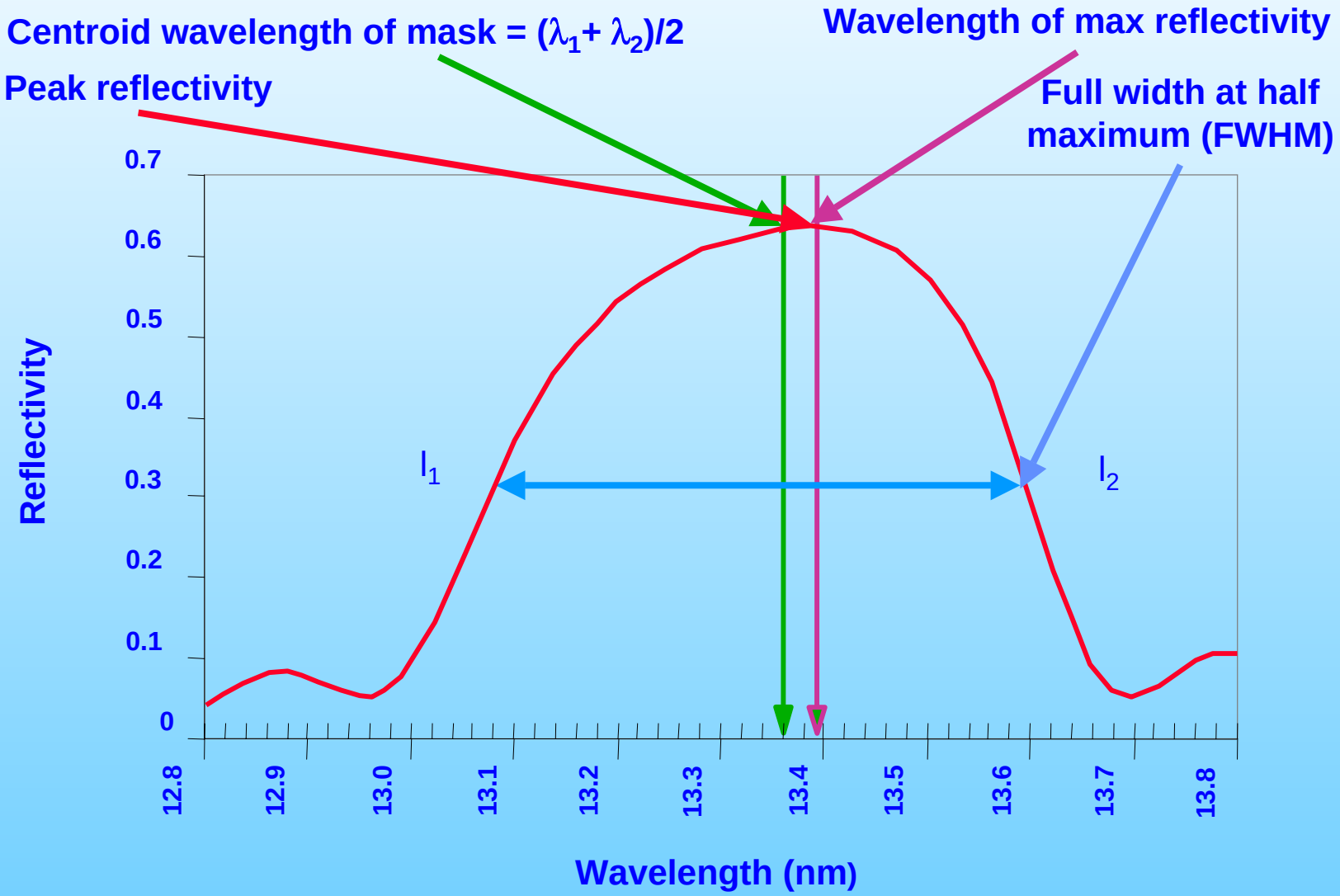
Wavelength calibration better than 1 pm RMS over the whole spectral range is achieved by reference to NIST published wavelengths of about 100 xenon emission lines. It is consistent with the wavelength of the krypton 3d-5p absorption resonance at 13.5947 nm to better than 2 pm.

The work was founded by the German Bundesministerium für Bildung und Forschung (BMBF).

View of the first system installed at SCHOTT Lithotec AG

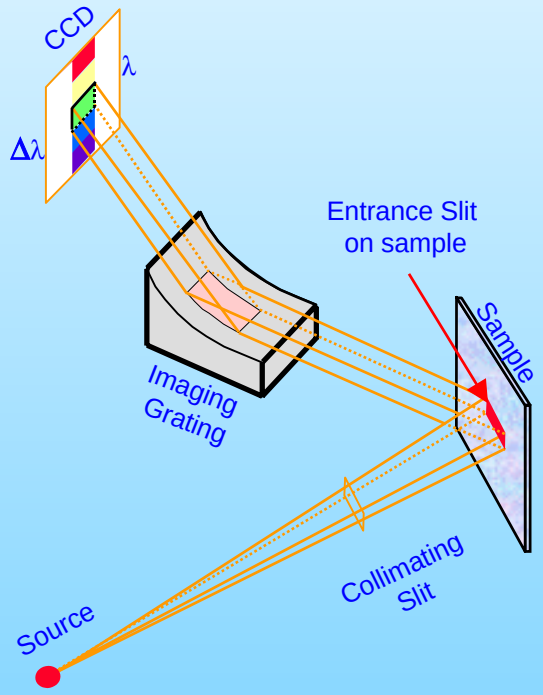
Clean room compatibility is realized by housing the tool and the use of special chosen liquid cooled components. The system is open at the top and the bottom for laminar flow.

Task: Measurement of SEMI Parameters of Mask Blanks



MBR uses the Polychromatic Reflectometry

Polychromatic (parallel)



Polychromatic reflectometry:
The whole EUV-spectrum is reflected by the sample, spectrally dispersed and detected by a multi-channel detector. The reference spectrum is obtained from the parallel measurement of reference mirrors.

Advantages:

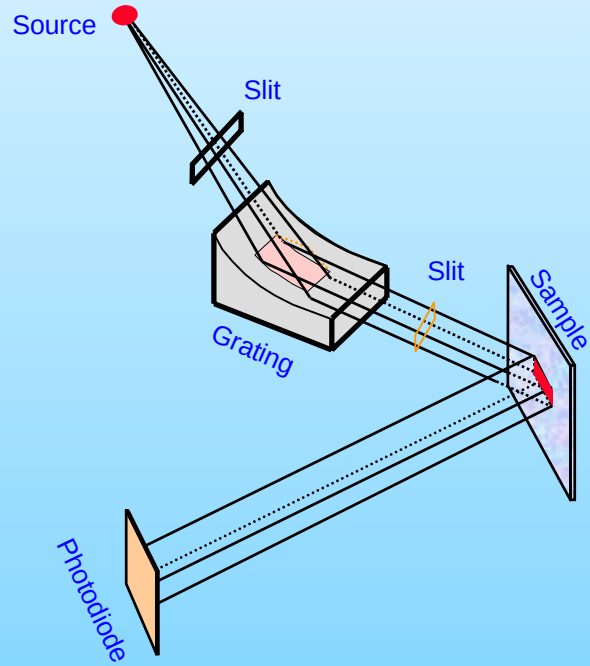
- All photons from the source are used
- The set-up is stationary
- With a CCD camera:
  - Good DQE
  - "Side-information" (scatter, geometry)
- The whole spectral reflectance curve is measured simultaneously. Hence, for measuring 2000 spectral channels with less than 1000 pulses
- Measuring system is mechanically stable.
- With reference mirrors any fluctuations do not influence the relative results.

Disadvantages:

- Instead of a diode: CCD camera: evaluation.
- Data transfer from the CCD limits the throughputs.

With the monochromatic approach, the light is dispersed first, one wavelength channel is selected by a slit and the sample is illuminated. The reflected light is detected by a diode.

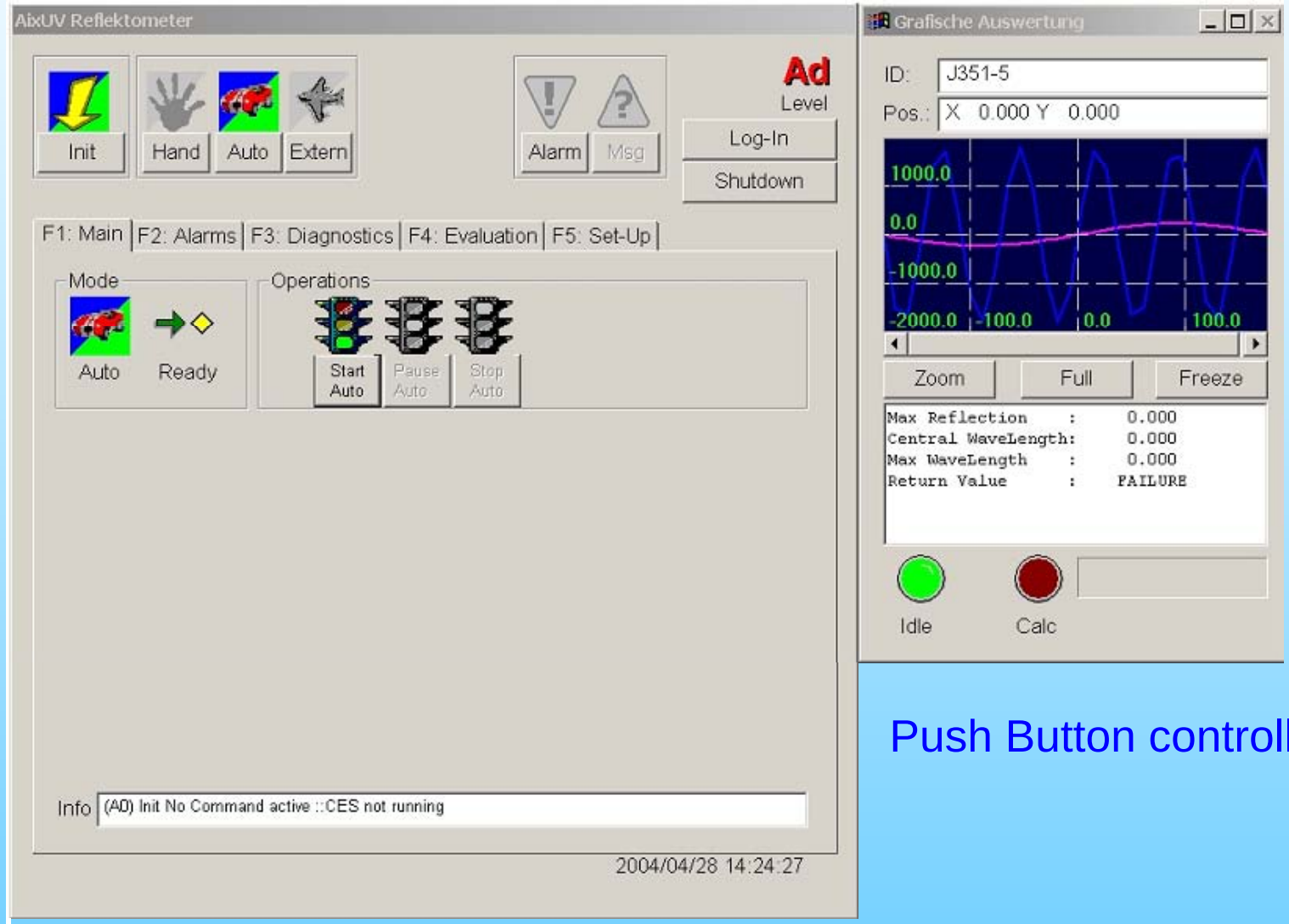
Monochromatic (sequential)



Performance of the MBR

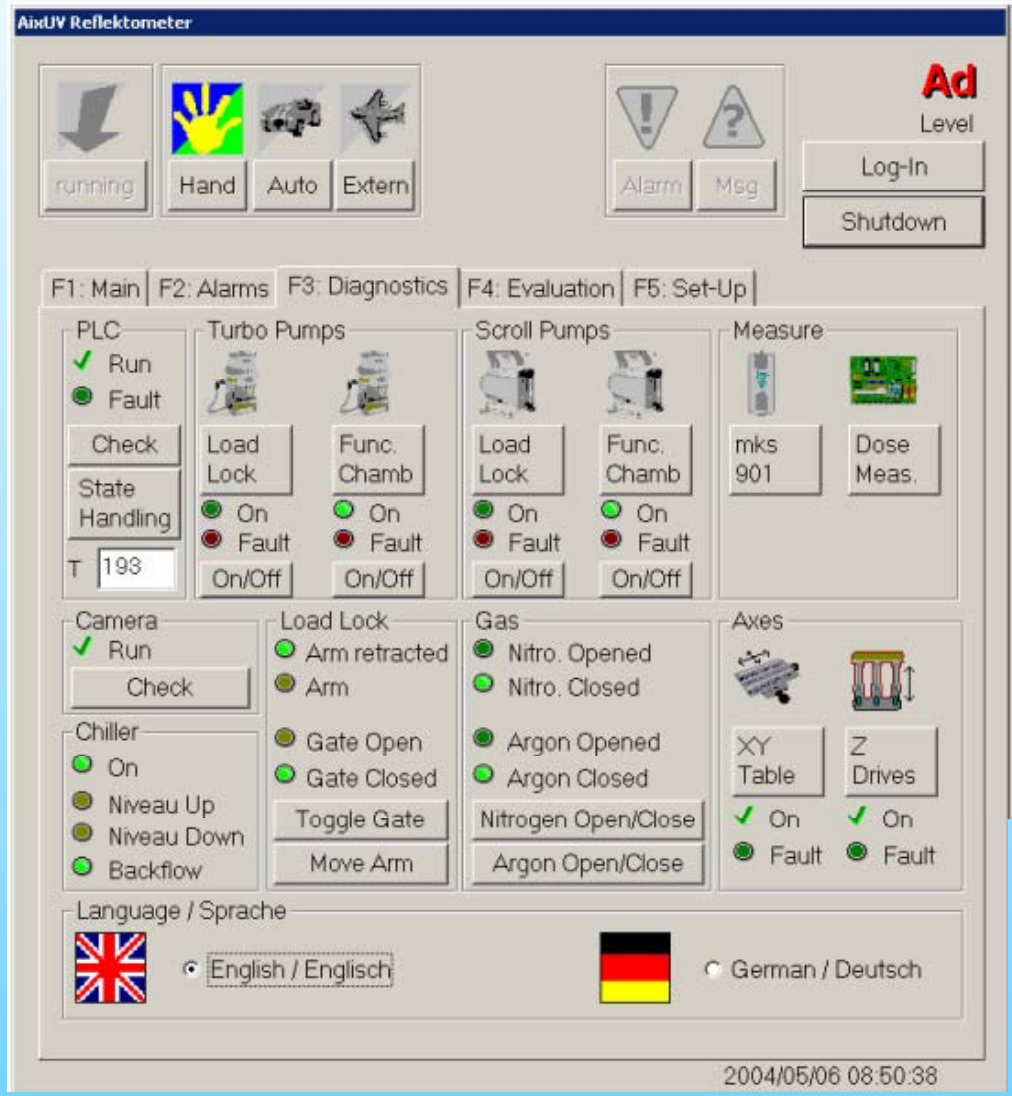
Parameter:	MBR achieved:
Spectral resolution	1.6 pm ($\lambda/\Delta\lambda$ > 3000)
Wavelength calibration: better	± 2 pm ($\lambda/\Delta\lambda$ > 3000)
Wavelength reproducibility better	± 1 pm ($\lambda/\Delta\lambda$ = 13.000)
Measuring spot size (Spatial sub-resolution within the 2mm)	< 100 µm ✕ 1 mm
Measuring spectral range	11.8 to 14.9 nm (2048 channels)
Time to measure one spot best quality	≤ 20 s (reflectors) ≤ 1 min (absorbers)
Throughput	3 samples per hour with 15 spots per sample
Angle of incidence reproducibility	< 30'' ⇒ $\Delta\lambda$ < 0.1 %
absolute accuracy (MADT)	< 0.5 % absolute
relative reproducibility of reflectance	< 0.2 % RMS
Contrast of measurement	> 11 bit with standard set-up > 12 bit achievable first allows to measure reflectances below 0.1 % on absorbers

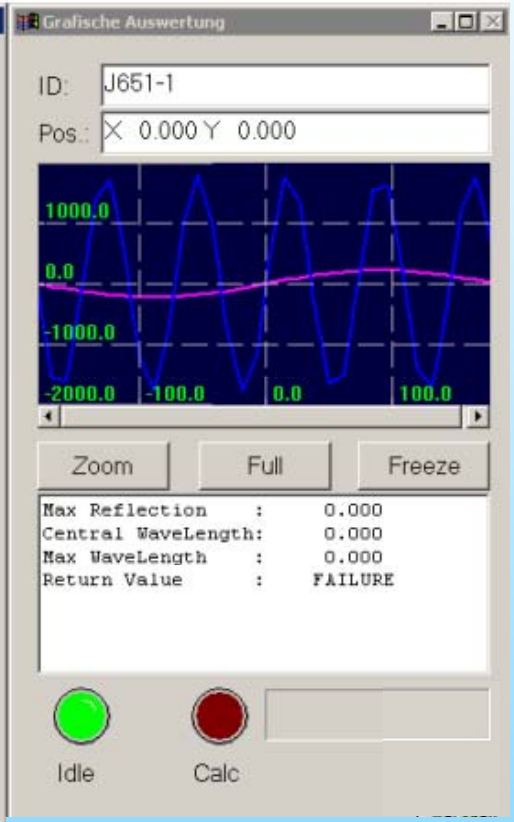
Simple user interface for standard operator



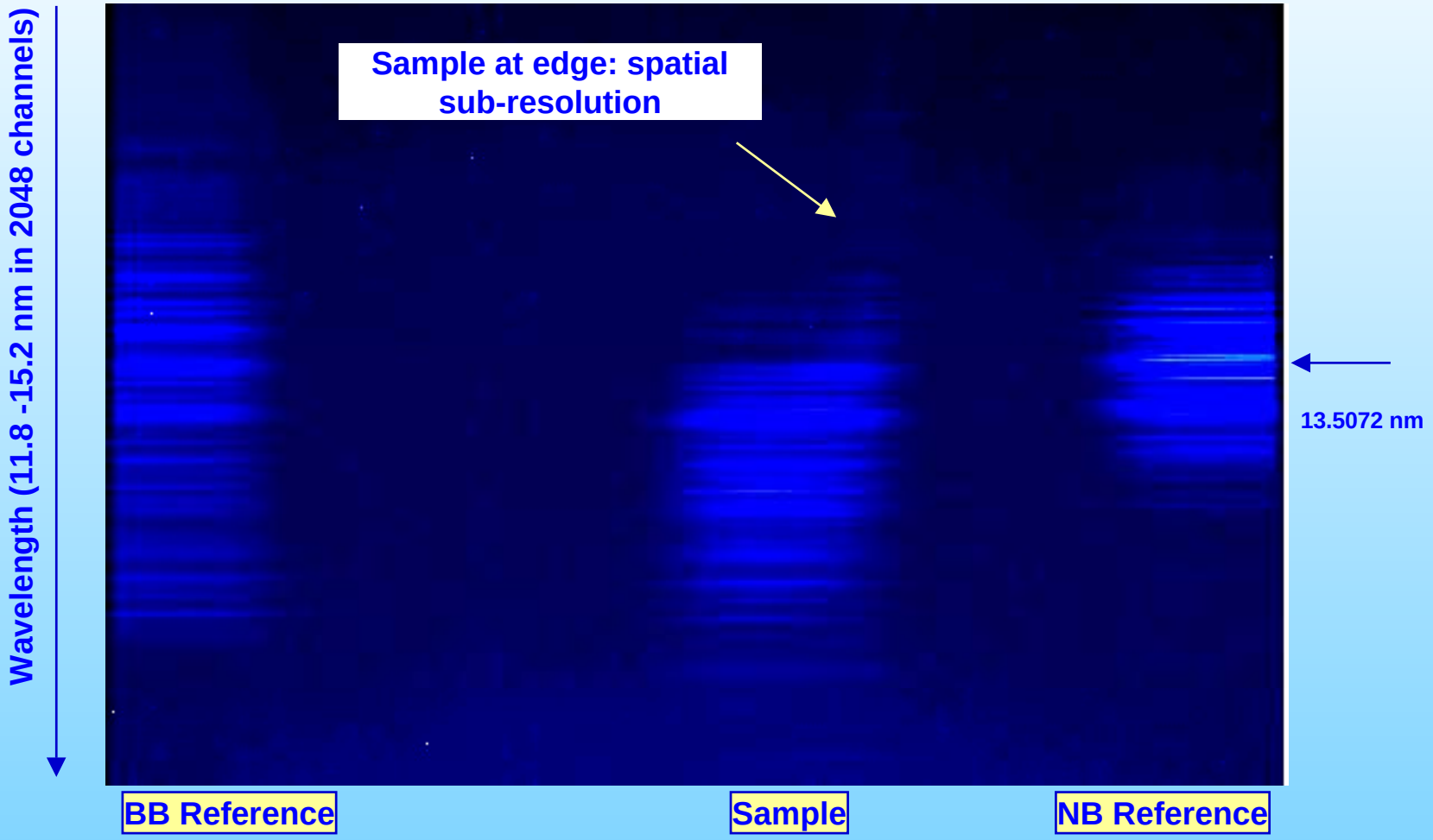
Push Button controlled operation

Tool owner and engineers can control every subsystem



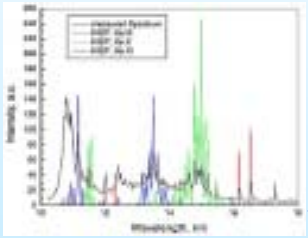


Spatial resolution of spectrograph



Focusing grating allows resolving of inhomogeneity within illuminated area.
This image was taken at the edge of the coating.

Rationals for high performance reflectometry



Wavelength reproducibility

Calibration by emission lines

Accuracy of Absolute Values

Measurement relative to calibrated mirrors

Adapted spectrograph

λ/Δλ > 3000 with special designed concave holographic grating

Reproducibility and Throughput

Photon statistics better 0.1 %

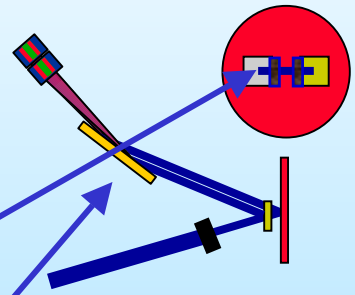
Small Measurement spot

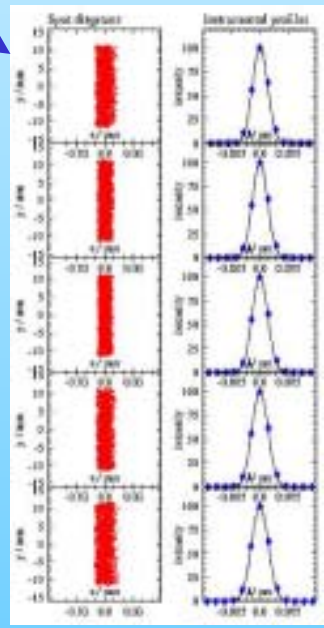
down to 20 µm ✕ 2 mm

Avoiding contamination

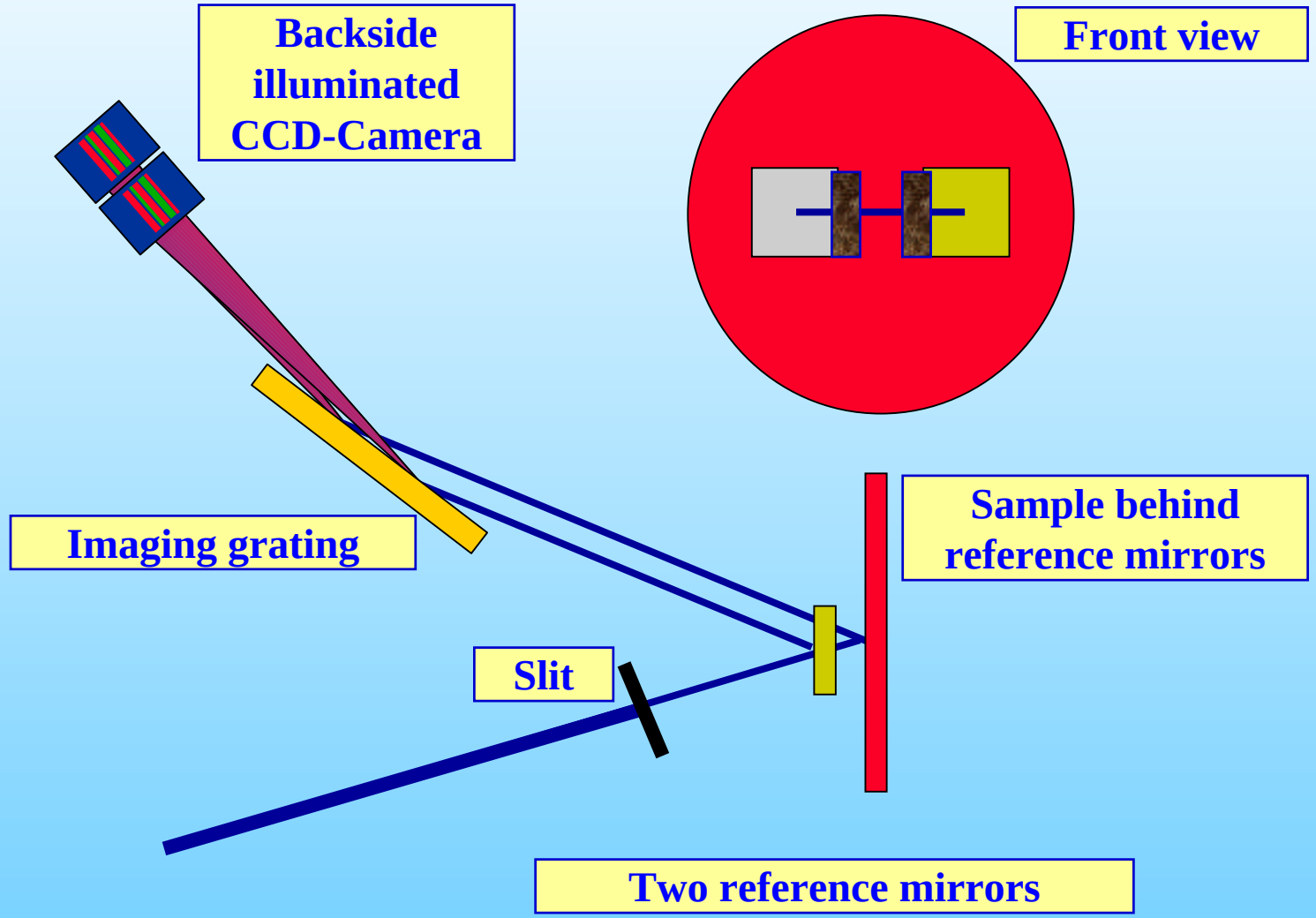
Background laminar gas flow,
Only sides contacts of blank

Contact with the mask is only at the bevels to avoid contamination and damage of the mask blank.





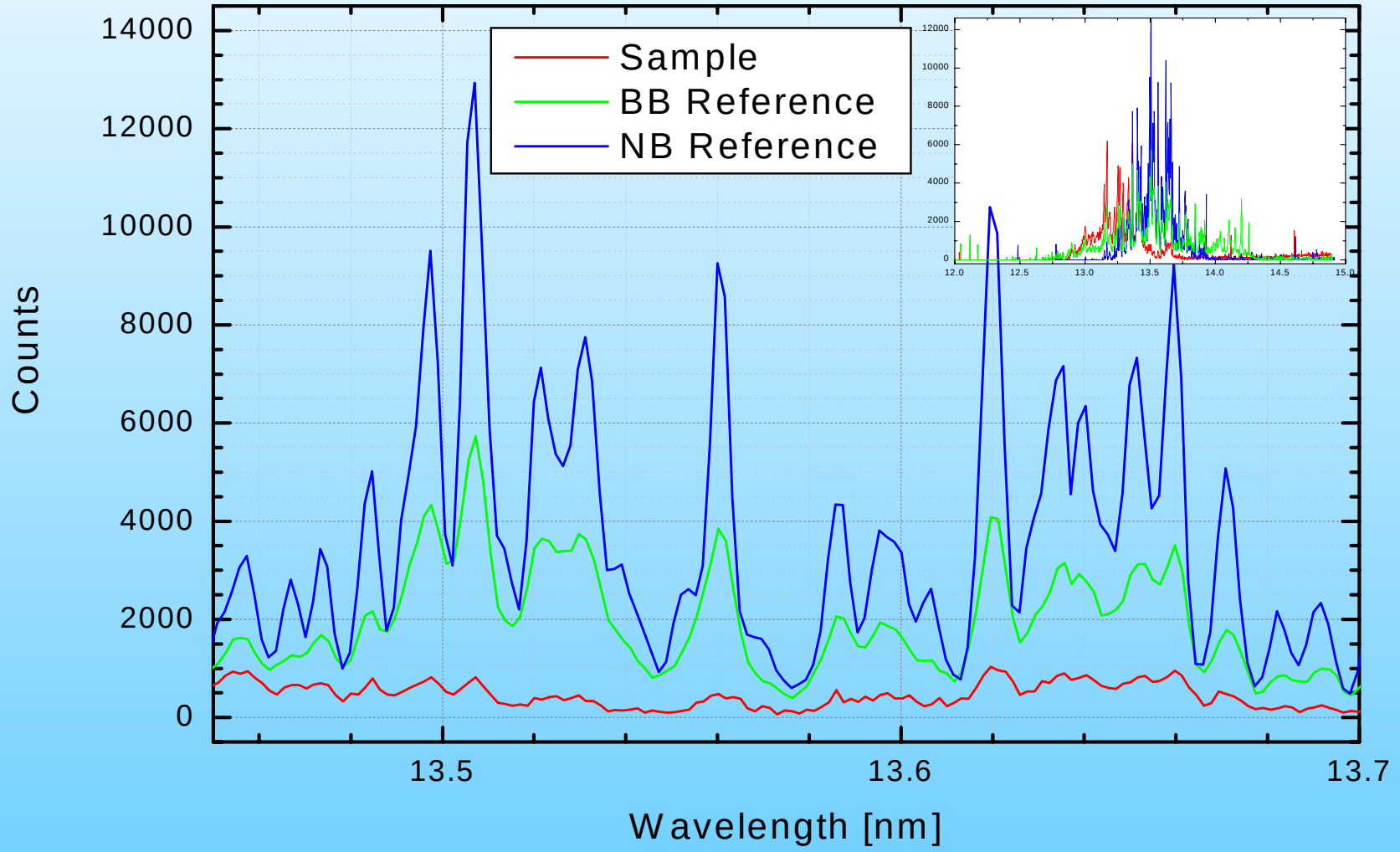
Schematic of Light Path in the MBR



Measurement of a calibrated sample allows to check calibration of MBR and re-calibration of reference mirrors

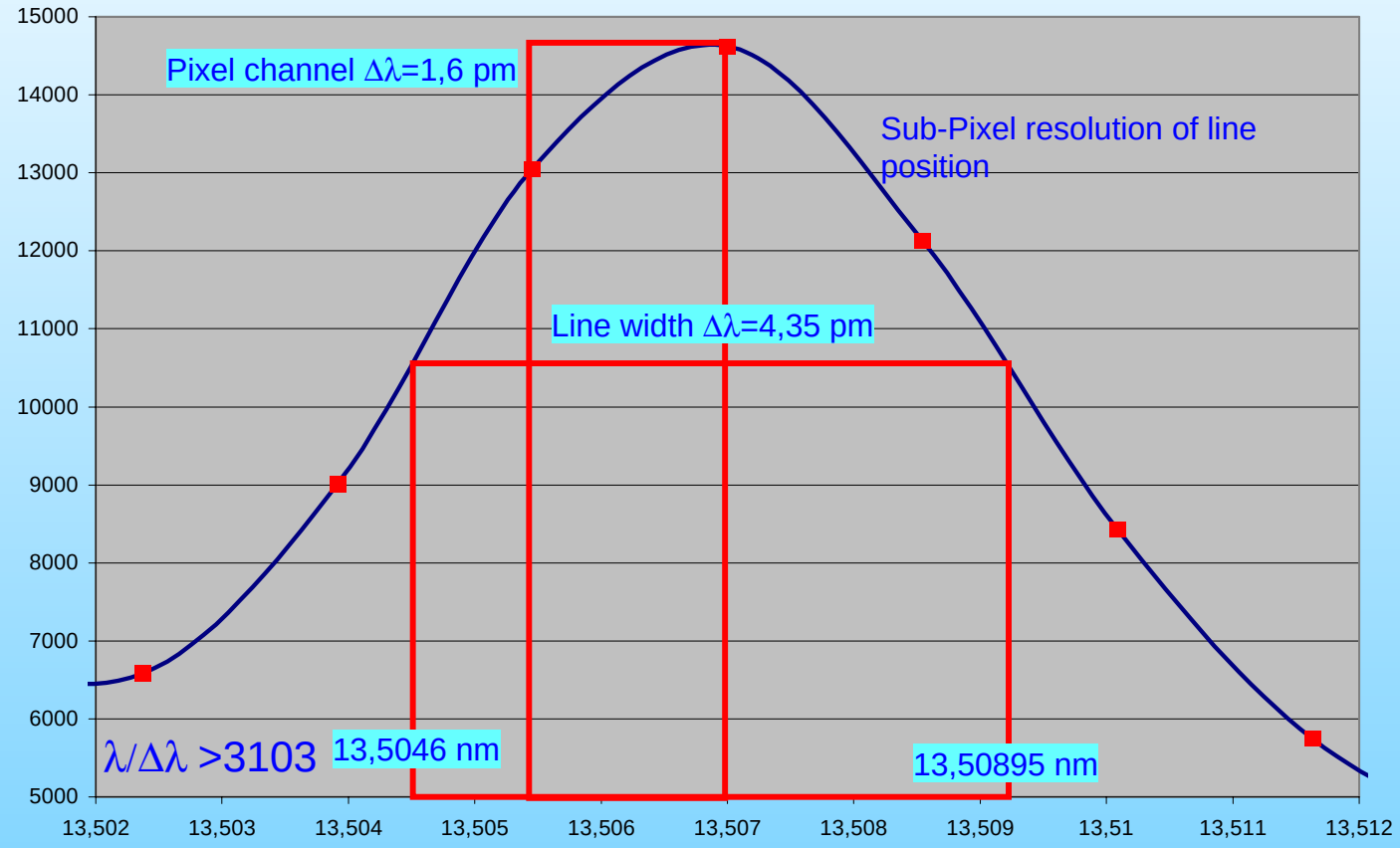
Raw-spectra of sample and both reference mirrors

The inset shows the range from 12 nm to 15 nm.



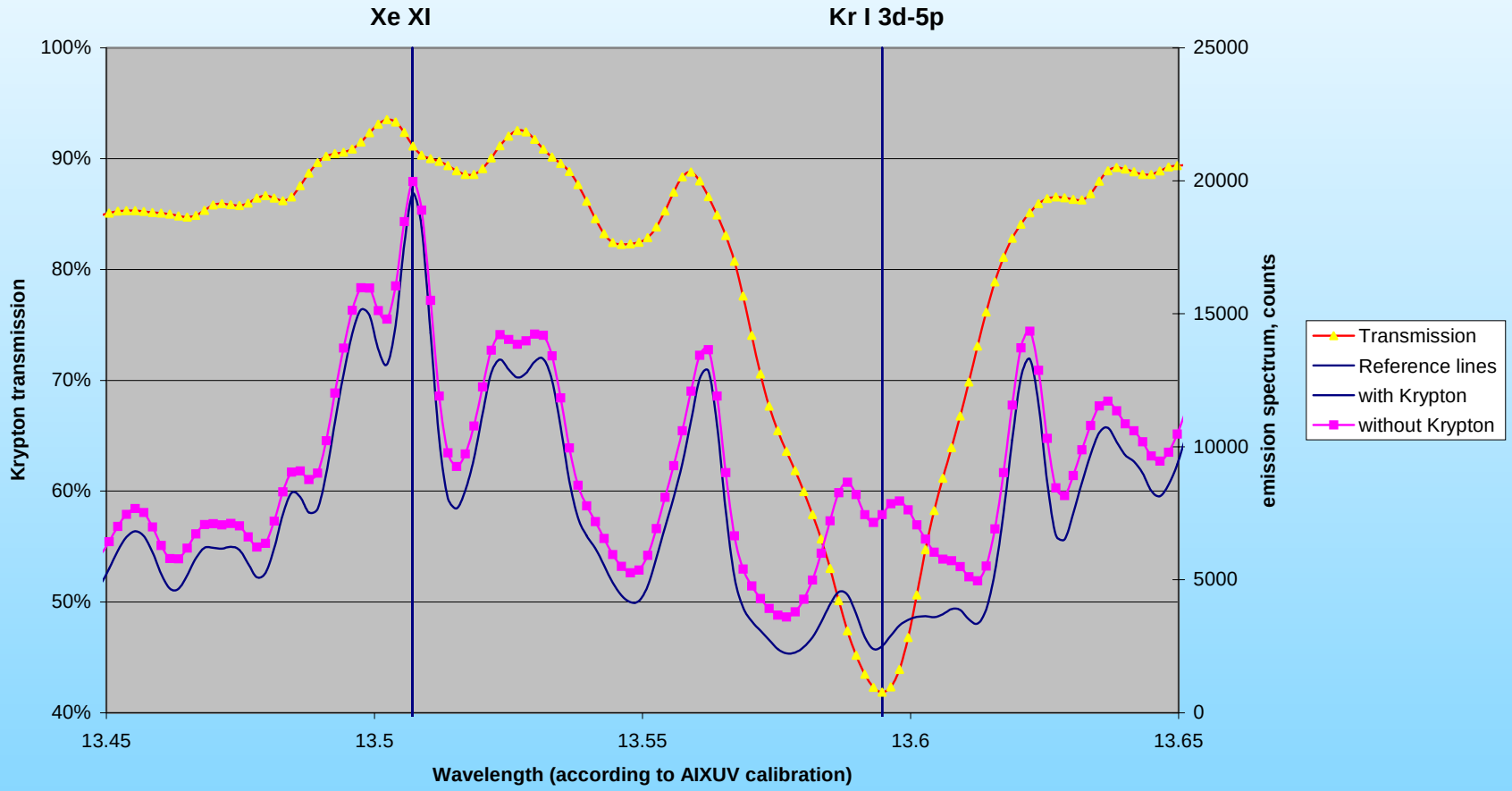
Wavelength accuracy of MBR build in spectrometer

Spectral channel of 1.6 pm allows to detect a single line as wavelength standard: HERE: Xenon 13.5072 nm line



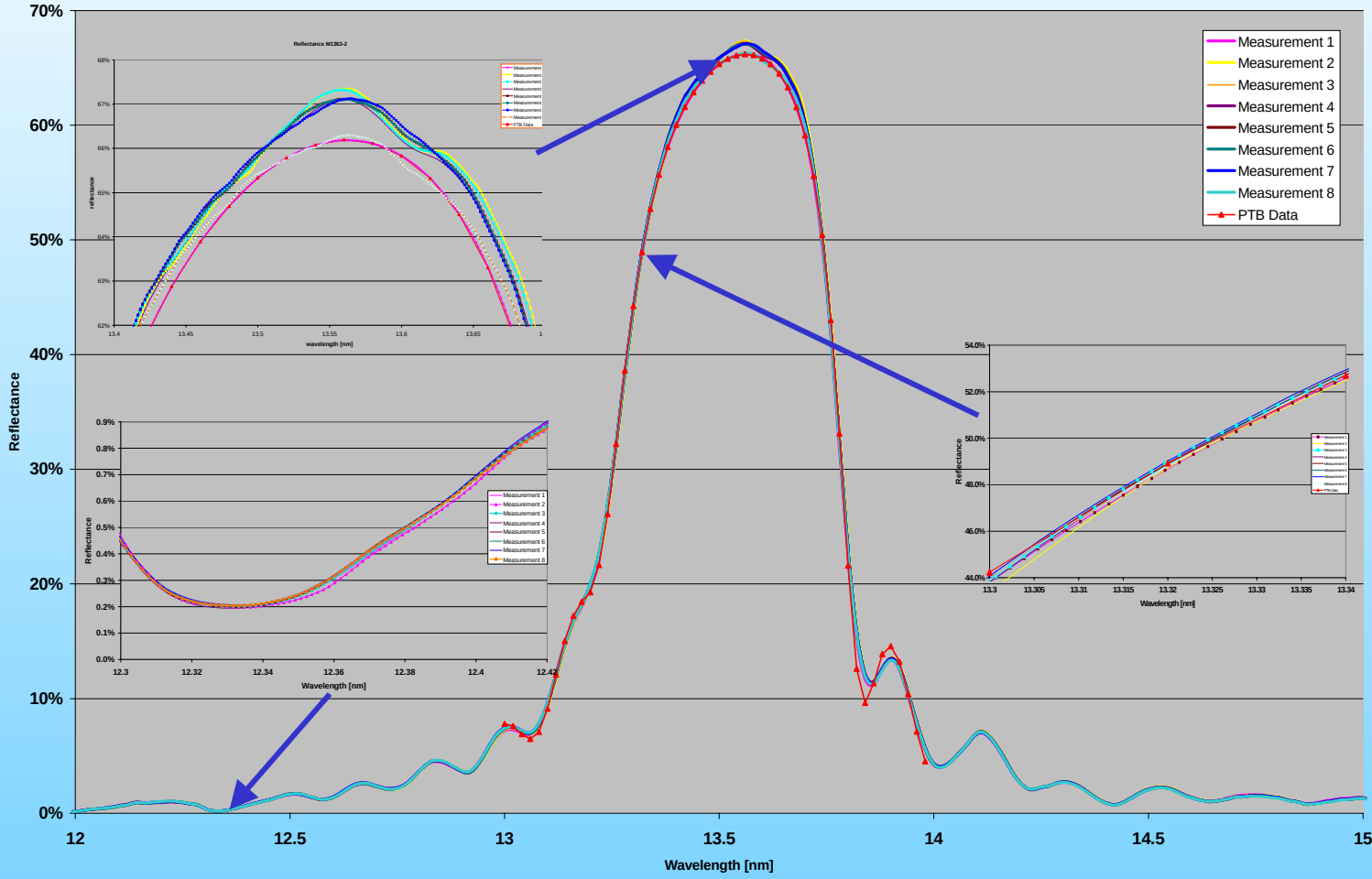
Upper limit for accuracy = resolution! (monochromator / spectrograph).
Design guideline $\lambda/\Delta\lambda \geq$ precision! 0.005 nm $\Rightarrow \lambda/\Delta\lambda \geq 2700$!!
Achieved: > 3000 !

Check of wavelength calibration with Krypton



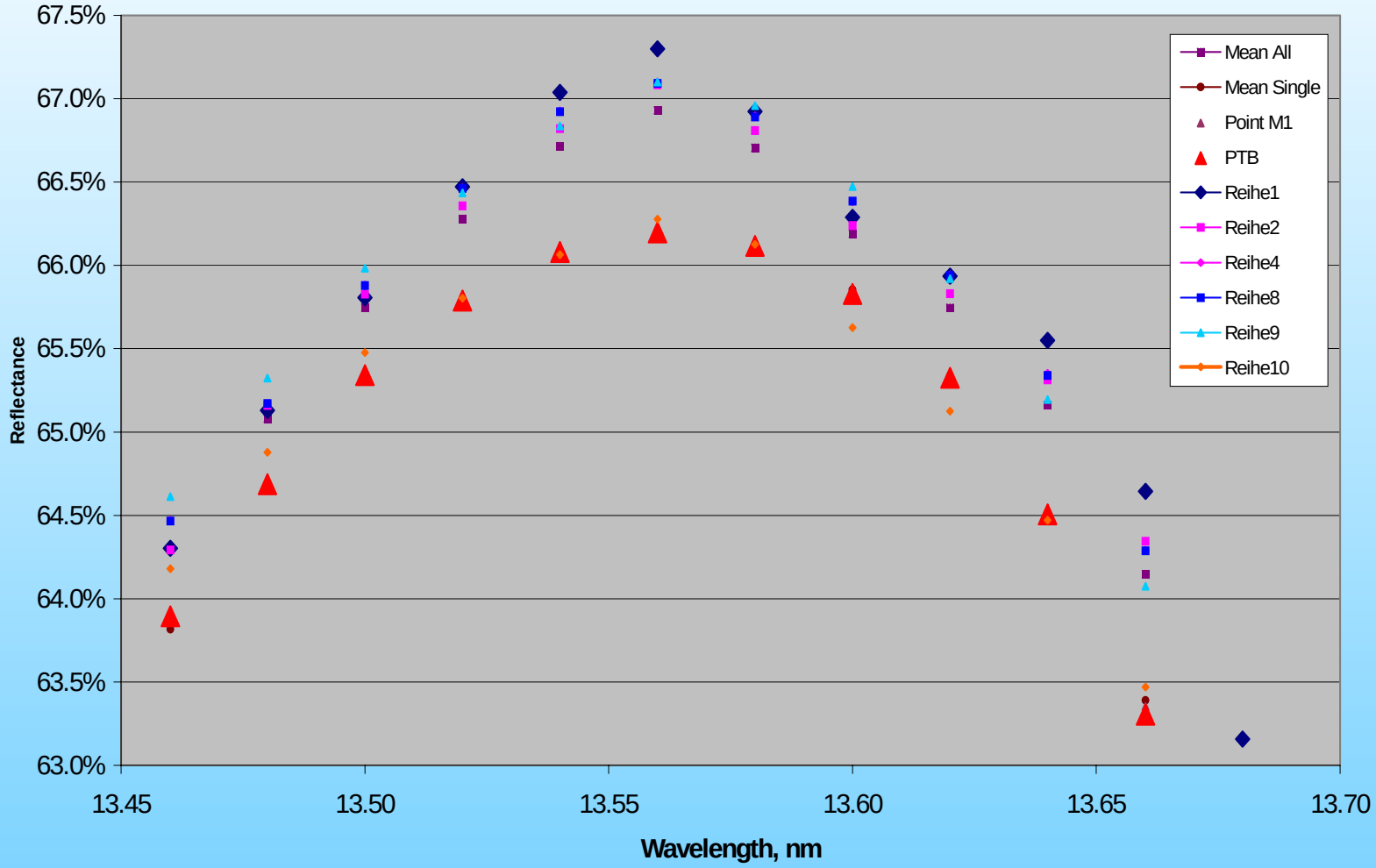
Wavelength scale checked with Kr 3d-5p resonance absorption line at 13.5947 nm. The wavelength scale was calculated using the emission lines. The position of the absorption line was found with less than 2 pm uncertainty.

Reproducibility



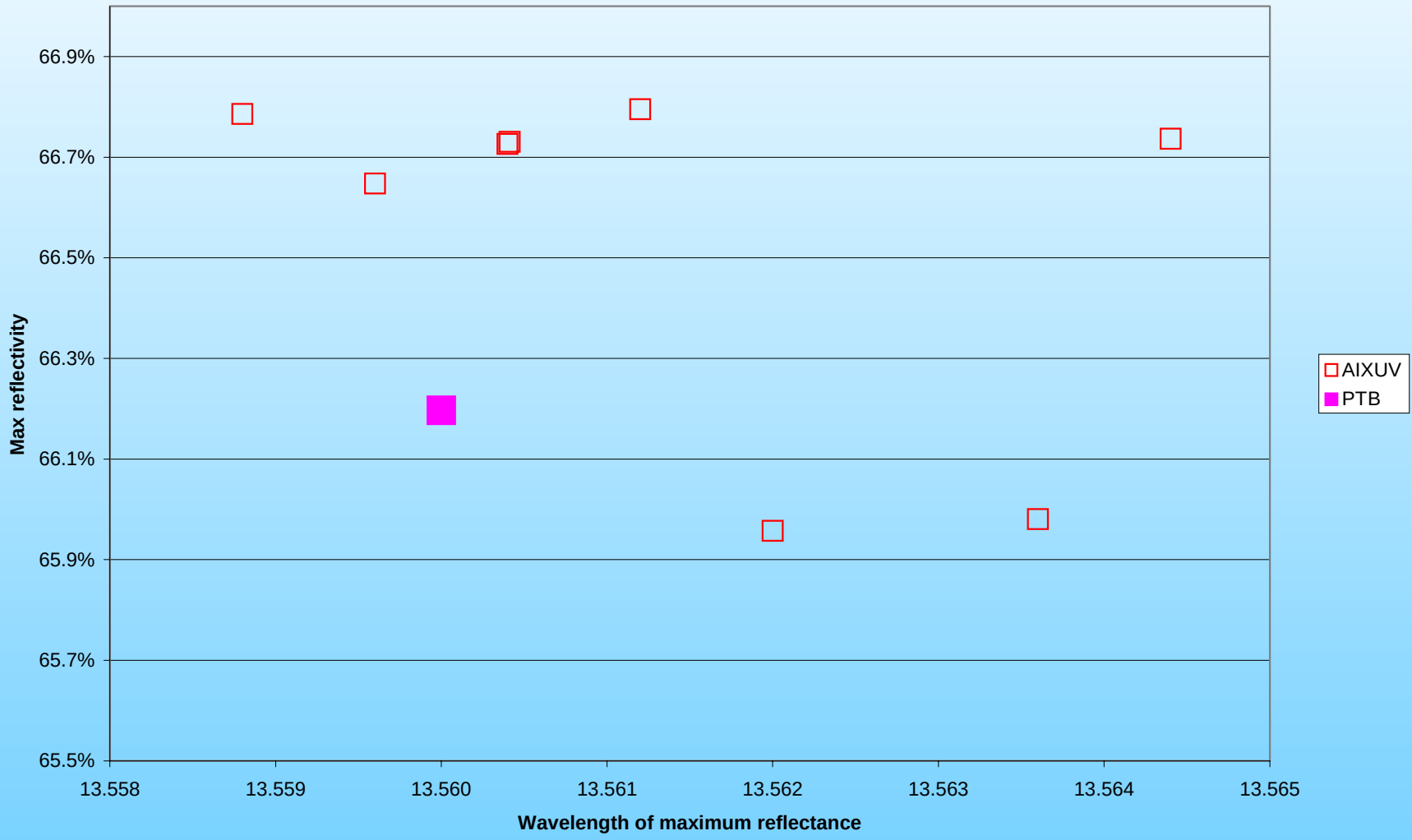
Reproducibility of the measurement of central wavelength, wavelength of max. reflectance and max. reflectance with the MBR demonstrated with 8 measurements.

Absolute Comparison PTB / AIXUV



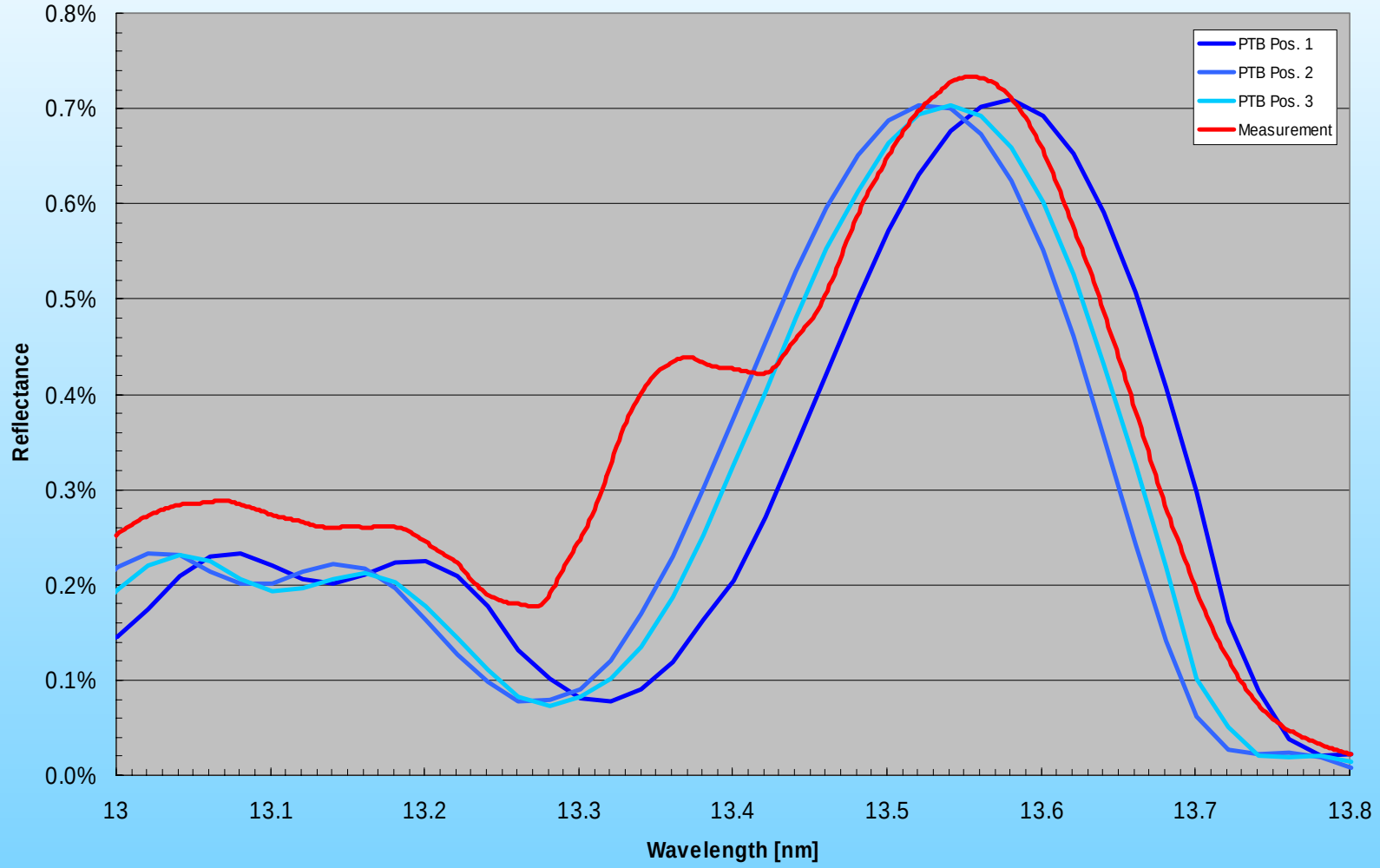
MBR data binned to same point distance is nearly as smooth as reflectance curve determined by PTB at BESSY II.

Absolute accuracy and reproducibility



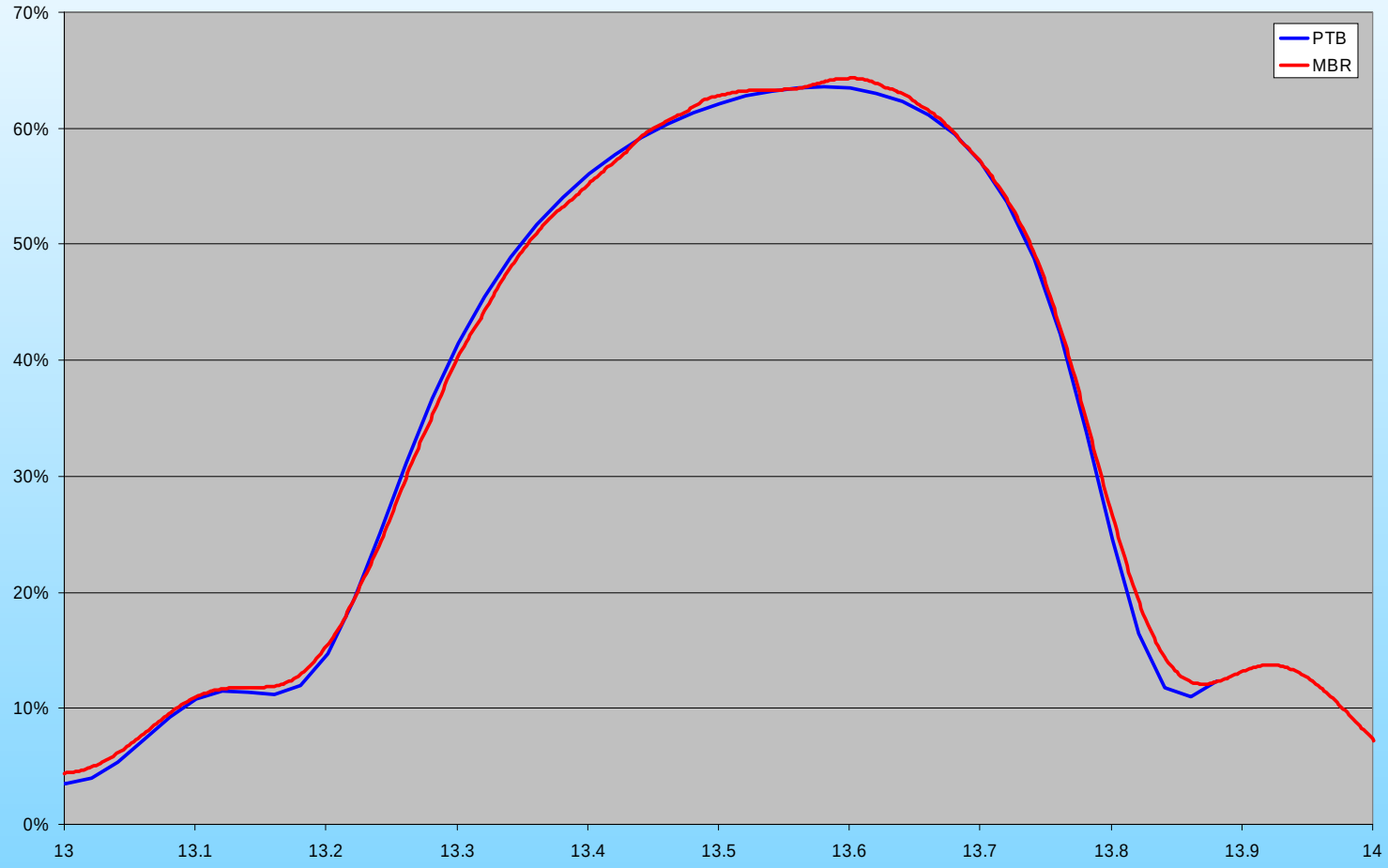
Absolute accuracy and reproducibility is demonstrated in series of measurements on same sample (2 different sites).

Measurement of Absorbers



Measurement of low reflecting sample (red line, 40 sec. of illumination) in comparison to PTB measurements at 3 different position on the same sample. The small peak at 13.34 nm was due to a reflex of visible light coming out of the pressure gauge.

Comparison to PTB Measurement at BESSY II

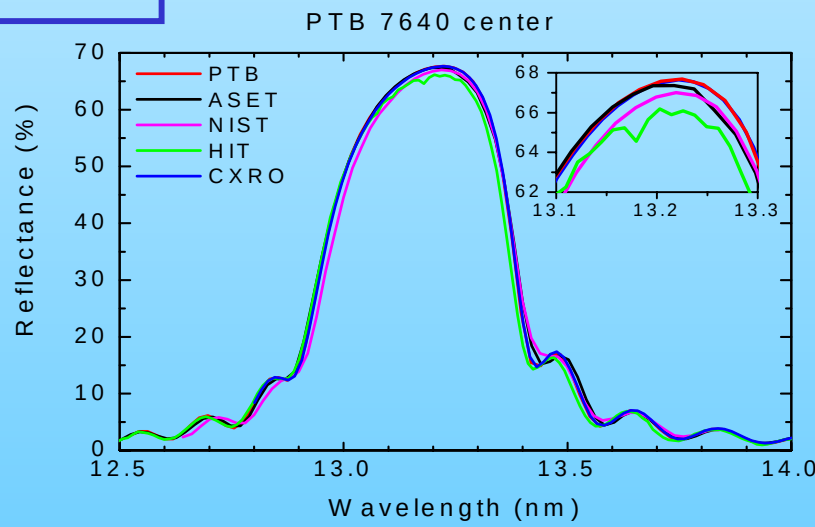


Reflectance curve measured with the MBR and compared to the same measurement done by PTB at BESSY II.

Comparison of different laboratories

	$\lambda_{central}$	R_{max} (absolute)
PTB	13,168 nm ± 0.0019 nm	67.72 % ± 0.1 %
CXRO	13.1684 nm ± 0.0019 nm	67.63 % ± 0.1 %
NIST	13.1763 nm ± 0.01 nm	67.03 % ± 0.35 %
ASET	13.1671 nm ± 0.002 nm	67.42 % ± 0.17%
HIT	13.16 nm	66.6 %
MBR	± 0.0016 nm	± 0.5 %

Comparison of the results of measurements of one single mirror at different laboratories.
In the table, the precision of the MBR, calculated from measurements of calibrated samples, is indicated.



$$MADT = \overline{X} - X_{\text{Target}}$$

MADT is the Mean Average Deviation from Target

AIXUV´s Reflectometer is 2nd Generation System, designed to fulfill requirements as in SEMI-Standard

a) One spectral channel of $\lambda/\Delta\lambda > 3000$ (300)

b) Small spot: 0.1 × 1 mm (2 × 2 mm)

c) Blank alignment

d) Fast stages

e) Maintenance free EUV-source

f) Engineered as a tool for Semiconductor industry

g) Fab-compatible Control Architecture

h) Direct verification at Mask Blank manufacturer (SCHOTT Lithotec)

Clean Room compatibility

The MBR is designed for clean room compatibility:

- stainless steel housing
- open at top and bottom for laminar flow
- most components are liquid cooled
- clean room compatible PC, keyboard and touch pad
- exhaust of valves is collected and guided into gray room
- roughing pumps and chiller are placed in gray room