Developments in NIST EUV Metrology

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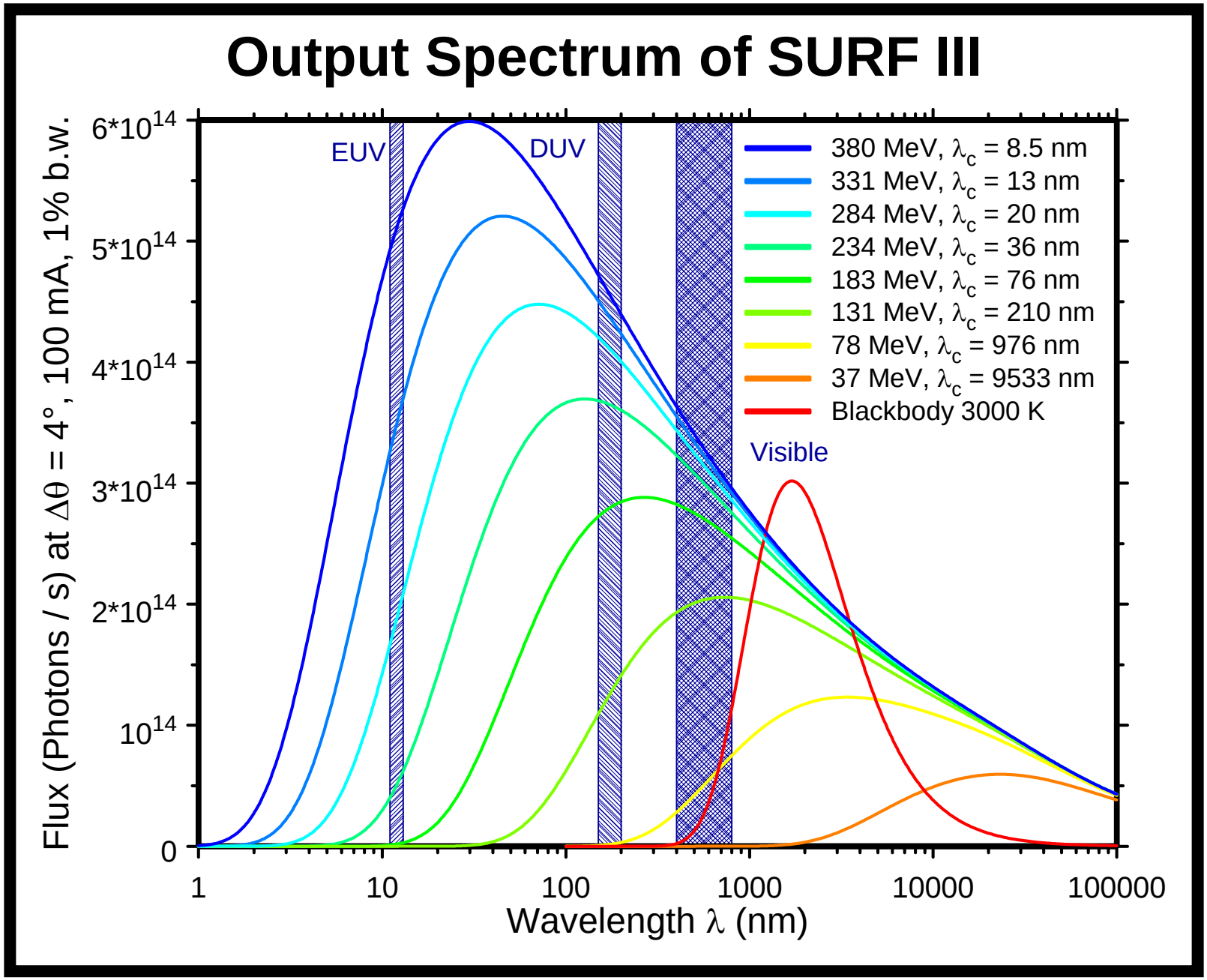
Introduction:

For decades The National Institute of Standards and Technology (NIST) has been providing metrology services in the extreme ultraviolet for industrial and scientific applications. In 2003, NIST has expanded its program to further meet the rigorous needs of Extreme Ultraviolet Lithography (EUVL). Changes in the program include reduced calibration uncertainties and expanded capabilities to include the calibration of assembled metrology instrumentation. Future work includes further improvements to wavelength accuracy and the inclusion of pulsed EUV calibration of assembled instrumentation.

SURF III

The measurements described here all utilized NIST's Synchrotron Ultraviolet Radiation Facility (SURF III). SURF III is a small, low energy storage ring dedicated to NIST's UV metrology needs. The relatively low electron energy of 380 MeV or less provides a peak output in the EUV regime. In addition, the electron beam energy is variable to suit the needs of individual users. This not only shifts the peak wavelength of the radiation but also controls the output of higher order radiation from monochromators. The beamlines at SURF III use this effect to control contributions of higher order radiation to characterize instruments and improve the accuracy of measurements by increasing the spectral purity of the light incident on a sample.

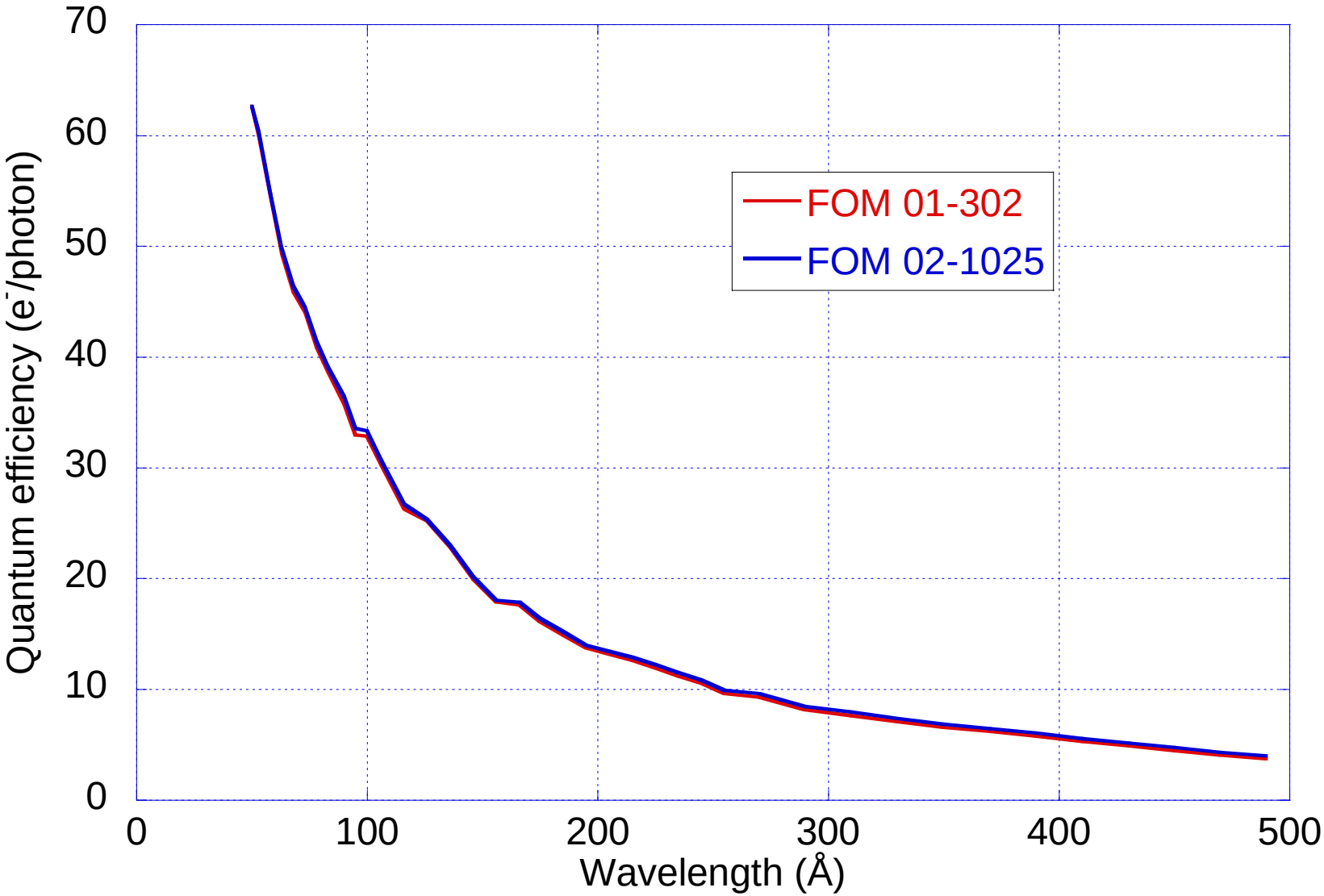

Output Spectrum of SURF III
Flux (Photons / s) at Δθ = 4°, 100 mA, 1% b.w.
6*10^14
5*10^14
4*10^14
3*10^14
2*10^14
10^14
0
EUV
DUV
Visible
380 MeV, λc = 8.5 nm
331 MeV, λc = 13 nm
284 MeV, λc = 20 nm
234 MeV, λc = 36 nm
183 MeV, λc = 76 nm
131 MeV, λc = 210 nm
78 MeV, λc = 976 nm
37 MeV, λc = 9533 nm
Blackbody 3000 K
1
10
100
1000
10000
100000
Wavelength λ (nm)

Improved EUV detector calibrations

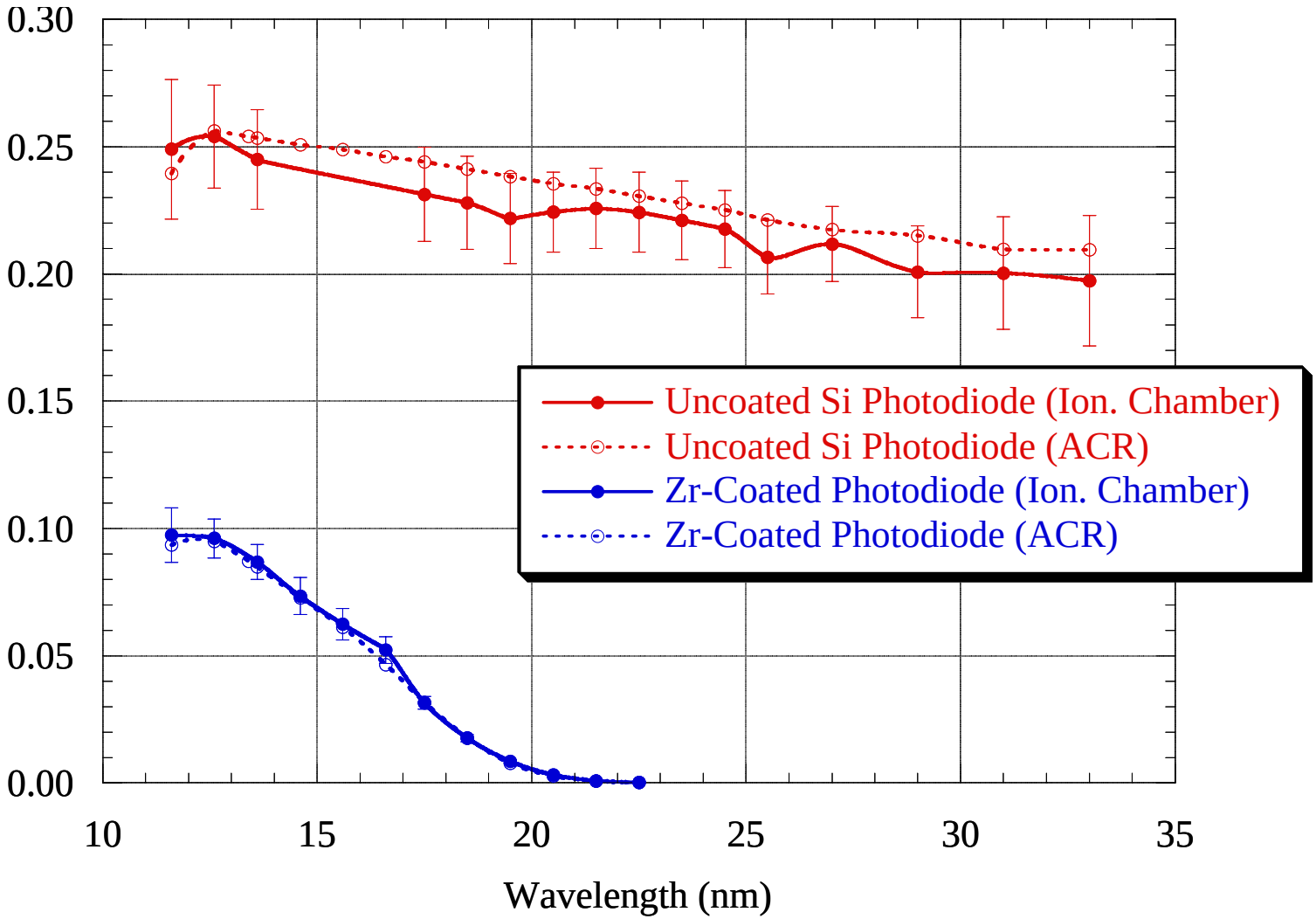
Until recently NIST's EUV detector calibration program has been based on a rare gas photoionization chamber. This resulted in detector calibrations with uncertainties of 4%* or higher in the EUV. In 2003, NIST upgraded the NIST/DARPA EUV reflectometry facility to accept endstations outside its large sample chamber. One of these endstations incorporated an Absolute Cryogenic Radiometer (ACR). An ACR is an electrical substitution detector that determines the power of incident light to an uncertainty as low as 0.1%. The ACR endstation was used for the calibration of EUV transfer standards for use on the NIST EUV detector calibration beamline. This improved the uncertainty of detector calibrations in the 13 nm regime to about 1%. This improvement not only reduces the uncertainty of detector calibrations (like those pictured to the left) but also the responsivity measurements of fully assembled metrology instruments like the Flying Circus (FC2) since they are directly compared to the same transfer standards.

*All uncertainties are given as the combined standard uncertainty with an average factor k=1.

FC2 Detector measurements



Photodiode responsivity traceable to ionization chamber and to ACR calibrations

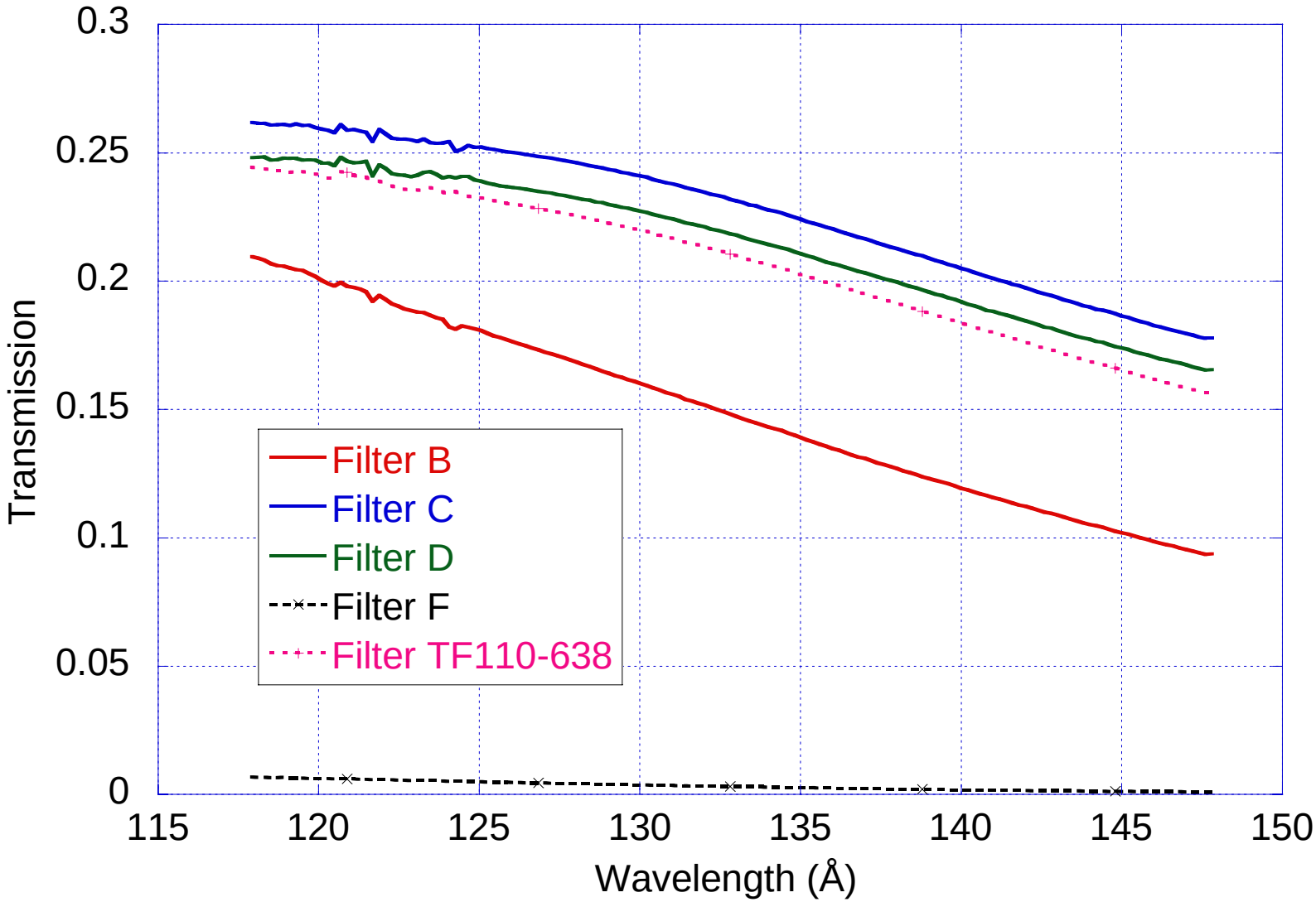


EUV mirror and filter measurements

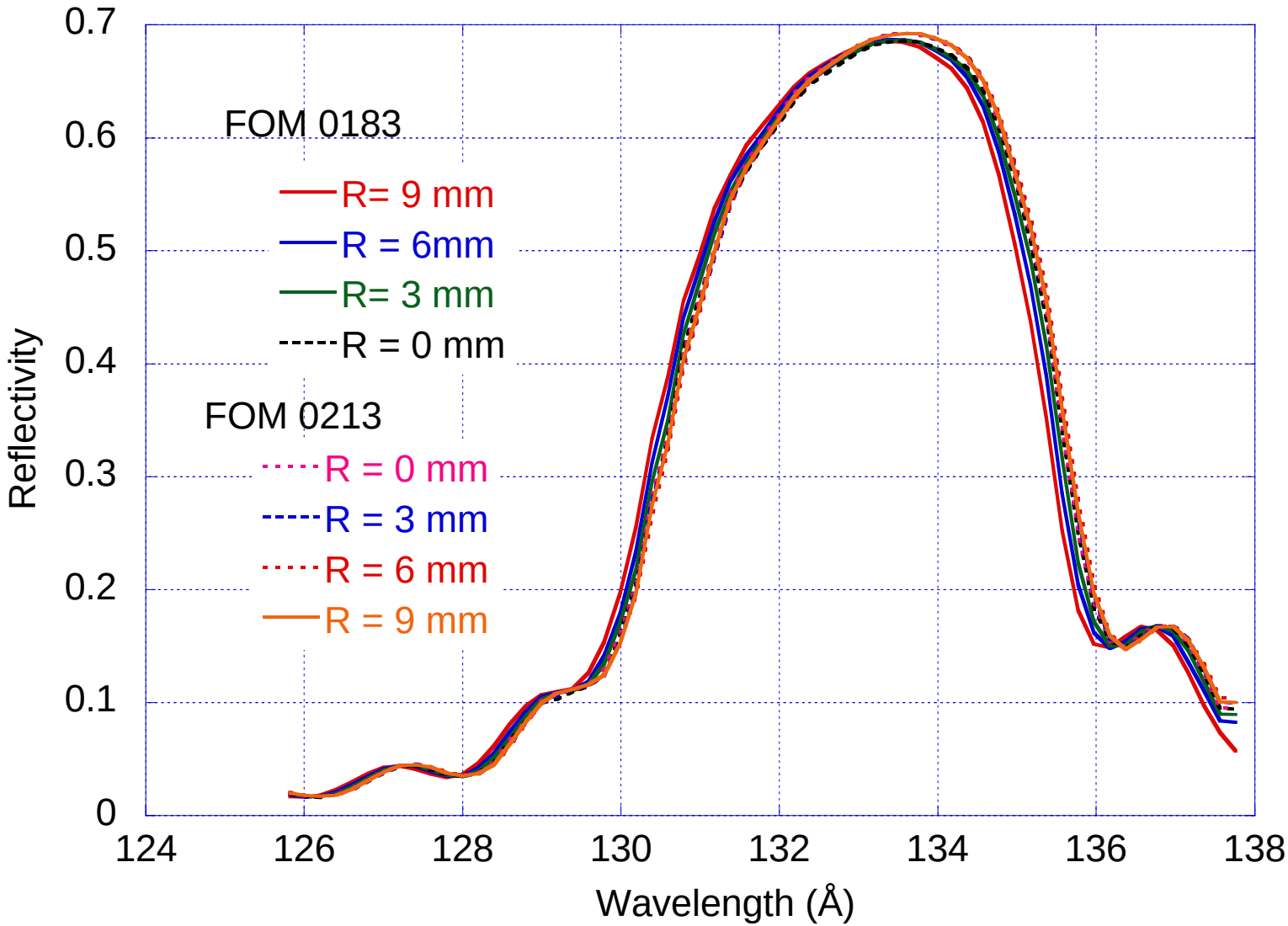
The NIST/DARPA EUV reflectometry facility has the capability to measure the reflection and transmission of samples up to 40 cm in diameter and 40 kg in mass. Its monochromator has a wavelength range of about 3-40 nm. The reflectometer has demonstrated accuracy of ~ 0.3% reflectivity with a wavelength uncertainty of up to 0.25 Å. Its double exit slit beam monitoring system allows for accurate normalization with uncertainty of ~0.1%. The figure to the right shows the reflectivity scan of two curved MoSi mirrors for use in the FC2. Filter transmission measurements can also be done on this beamline with a 1% uncertainty. Examples of these measurements are shown in the left hand figure which contains transmission scans of several Zr filters of various thicknesses for use in the FC2.

Transfer optics can be added to the large sample chamber to allow for the use of external endstations to expand the capabilities of the instrument including detector calibrations and responsivity measurements of assembled instruments. A two phase upgrade of the monochromator will begin this summer to improve wavelength resolution, accuracy and stability.

FC2 filter measurements



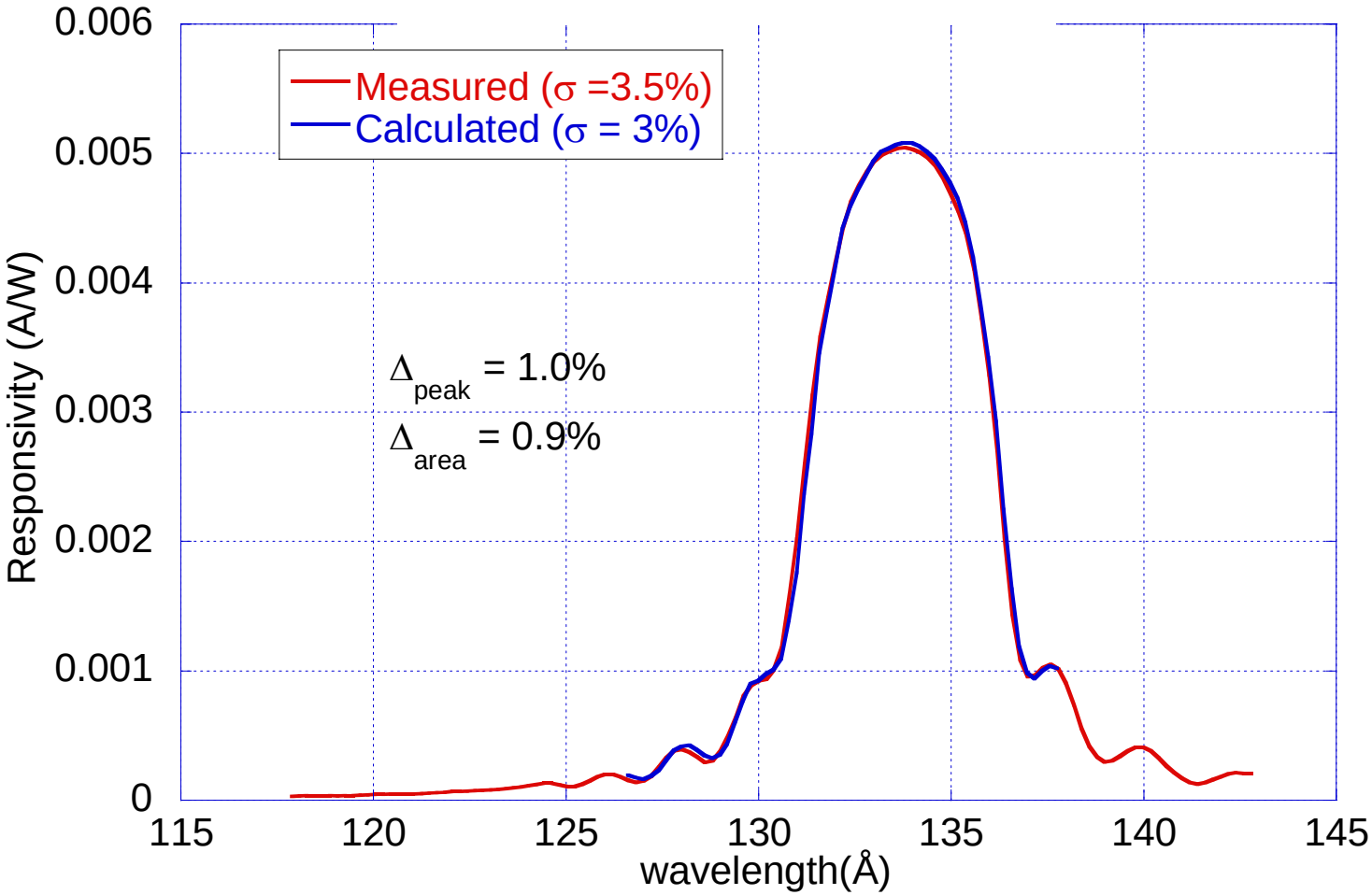
FC2 mirror measurements



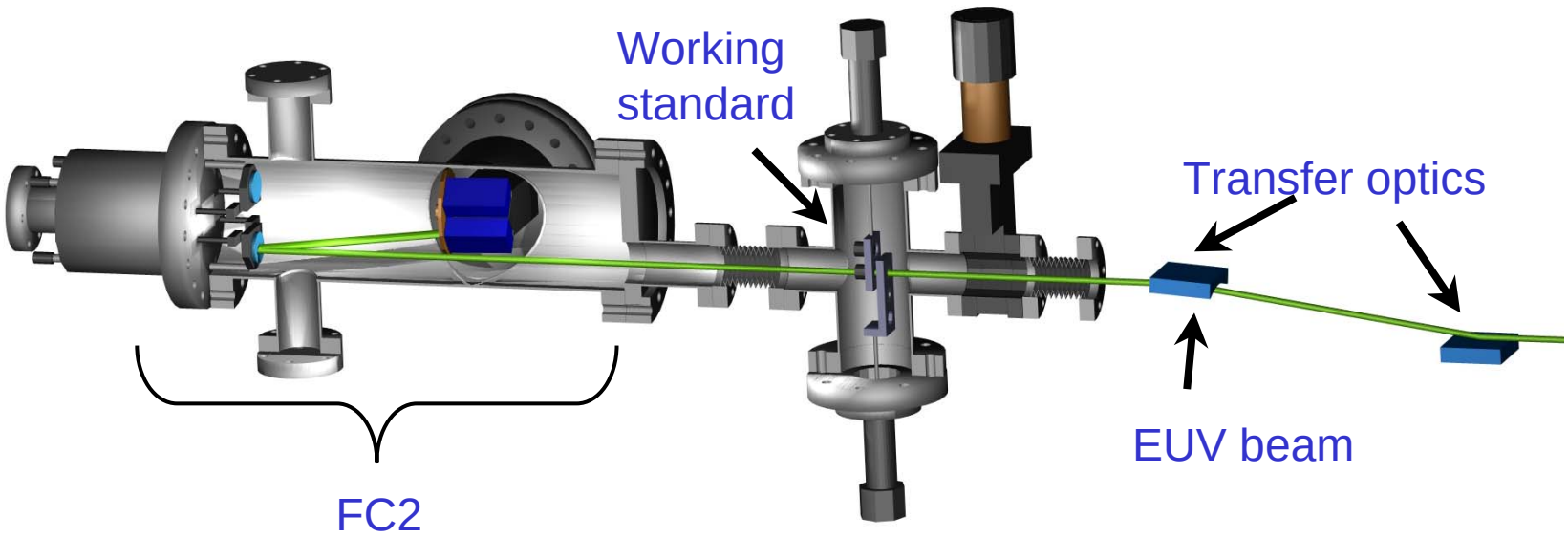
Measurements of assembled EUV instrumentation

NIST's most recent development is the capability to measure the responsivity of a fully assembled metrology instrument. In December 2003, NIST conducted the first measurements on an assembled FC2. This was done by utilizing in-vacuum transfer optics to relay EUV radiation from the reflectometer sample chamber into an external endstation. Beyond the sample chamber the endstation housed a removable calibrated transfer standard followed by the FC2. Measurements were conducted by placing the working standard in to the incident beam and transferring its calibration to the double slit beam monitor of the reflectometer by scanning the wavelength of the monochromator and recording the ration of the two detectors. The working standard was then removed from the beam path and light was brought in the FC2 where it was directed onto its detector. The calibration of the beam monitor was then transferred to the output of the FC2. This cycle was repeated for various configurations and filter combinations to fully measure the instrument's performance. The graph below shows a comparison of the measured responsivity of the assembled FC2 and calculations based on the measurements of the performance of elements internal to the FC2 including filters, mirror and detector. The example shows excellent agreement in both peak and integrated comparisons. All the measurements and calculations of the FC2's responsivity agreed to within the uncertainties of the measurements and were typically on the order of 2.5% and never exceeded 4.2%.

Assembled FC2 responsivity measurement



FC2 on the NIST/DARPA Reflectometer



Future plans:

- Reflectometer monochromator upgrade.
- Improved second order wavelength suppression for detector calibration beamline.
- Laser-produced Plasma-based responsivity measurements of an assembled FC2.
- SURF III-based responsivity measurement of a JENOPTIK Energy-Monitor instrument.
- Development of Al_2O_3-based detectors for pulsed source monitoring.
- Characterization of EUV detector performance under pulsed irradiation.
- Improved control of transfer optics to reduce spot size.

Summary:

The National Institute of Standards and Technology has expanded and improved its EUV metrology program to aid in the development of EUV sources to fit the needs of EUVL. Future work will further improve the capabilities and uncertainties of the available techniques and help improve metrology throughout the EUVL community.

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