

Evaluation of components and tools for pulsed EUV source radiometry

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Abstract

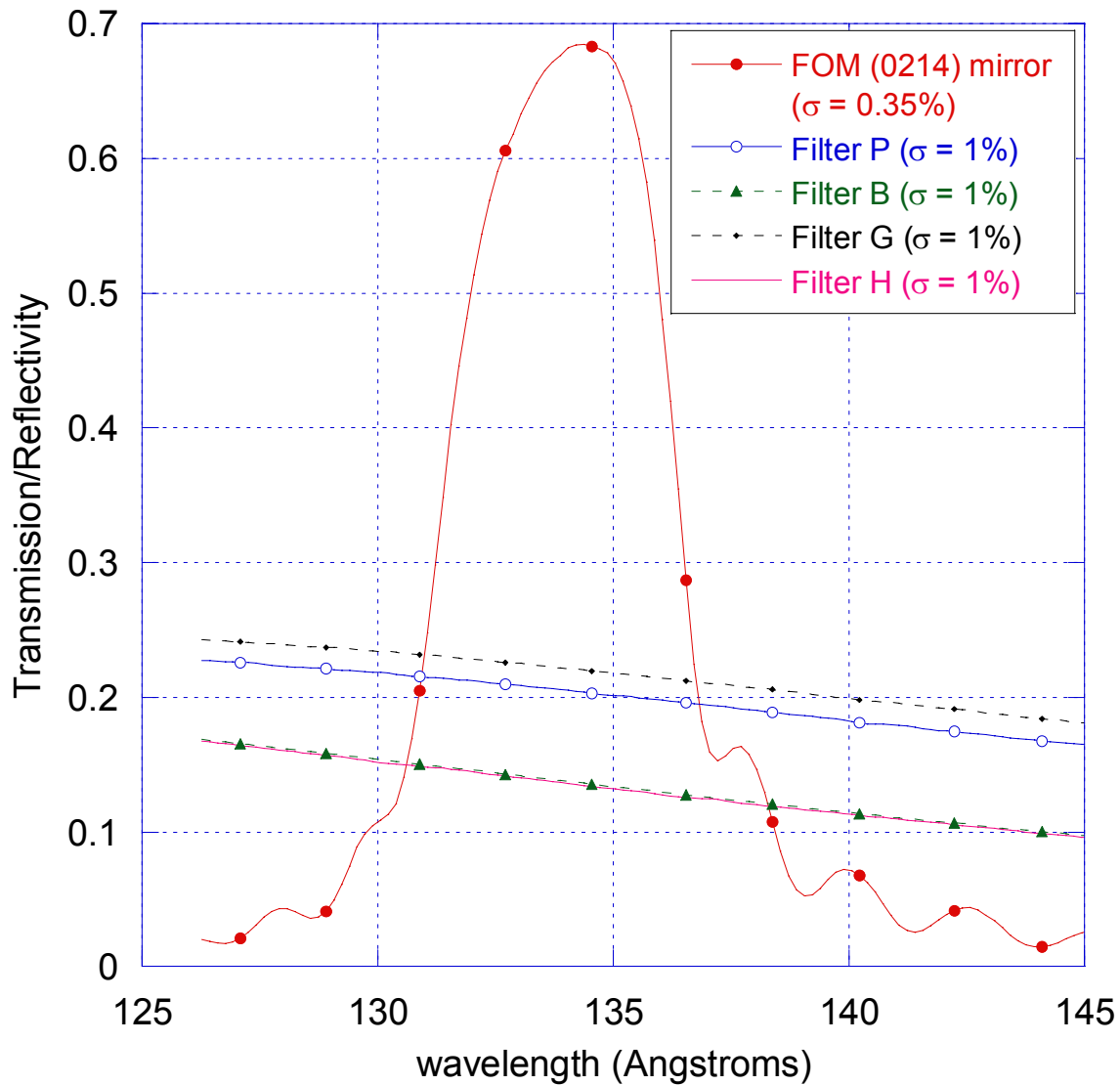
NIST has provided VUV metrology for more than four decades for detectors used in astronomy and, more recently, in EUV lithography. Traditionally these calibrations have been conducted with synchrotron radiation, effectively a cw source since the pulse period is much less than the detector's impulse response time. NIST's current synchrotron radiation facility, SURF III, is a stable broadband source that is ideal for EUV component characterization and calibration. However, the field of EUV lithography relies on pulsed plasma sources that generate high-powered EUV pulses with multi-kilohertz repetition rates and durations below 100 ns. When the calibration source and the plasma source differ so greatly it is necessary to evaluate the applicability of a calibration for the source conditions present in real world measurements. In this poster we will present NIST's EUV component and tool calibration effort including both synchrotron radiation and laser-produced plasma-based measurements. In addition, we present an evaluation of a photoemissive EUV detector in a laser-produced plasma environment along with visible light experiments that provide a basis for determining the limits of cw calibrations used under pulsed-illumination conditions.

EUV component calibration

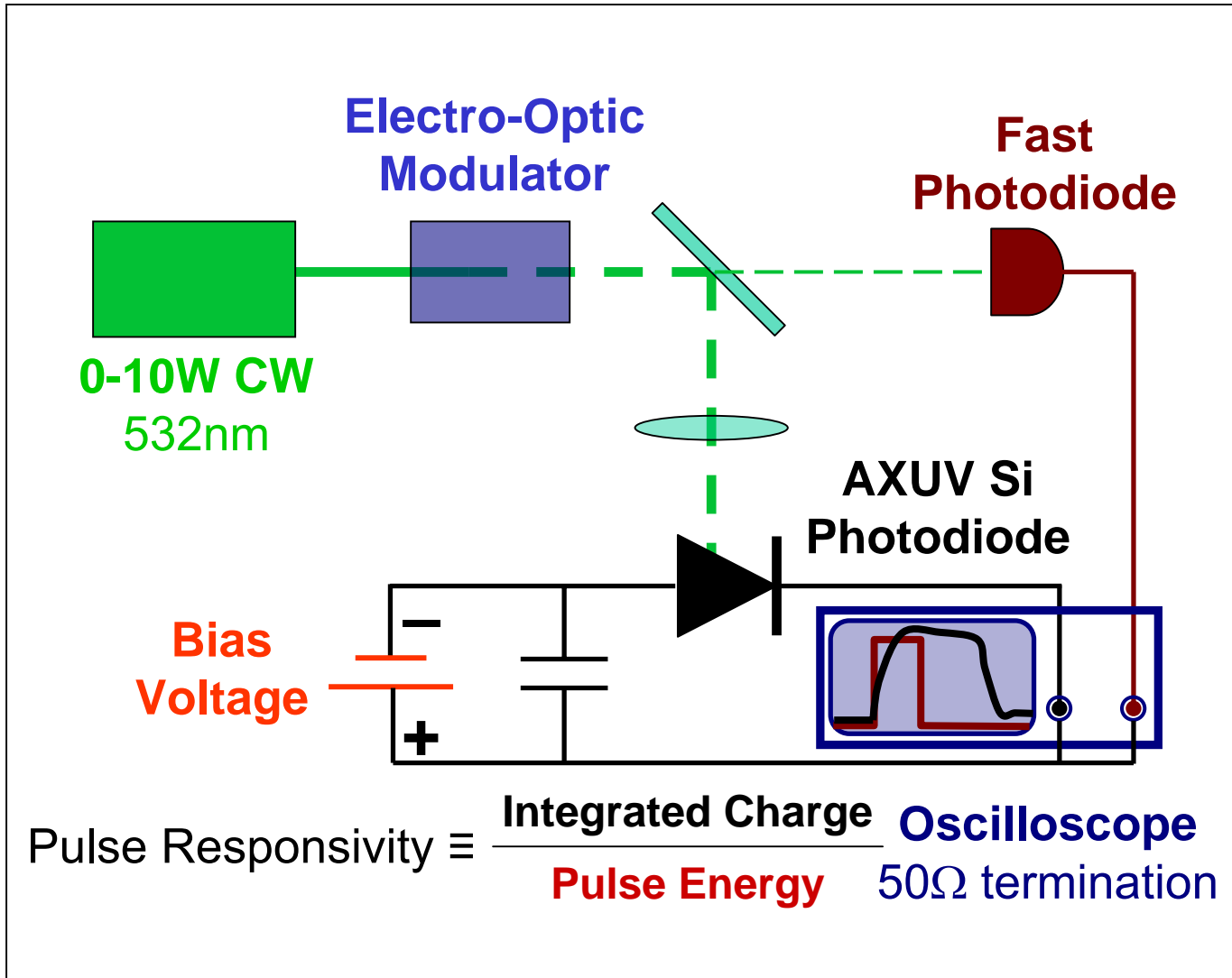
- Calibrations done at SURF III.
- NIST/DARPA EUV reflectometry facility:
 - Wavelength uncertainty: 0.01 nm.*
 - Reflectivity uncertainty: 0.35%.
 - Max. sample size: 40 cm dia., 40 kg mass
- Filter transmission: 1% uncertainty.
- SURF III EUV detector calibration facility:
 - Absolute Cryogenic Radiometer (ACR) -based working standard
 - Absolute uncertainty: 1.0%.

*All uncertainties are given as the combined standard uncertainty with a coverage factor $k=1$.

FC 2 mirror and filter data



Note: The measured peak is shifted due to the high angle of incidence necessary for the NIST measurement, under normal use the FC2's responsivity is nominally at 135Å.

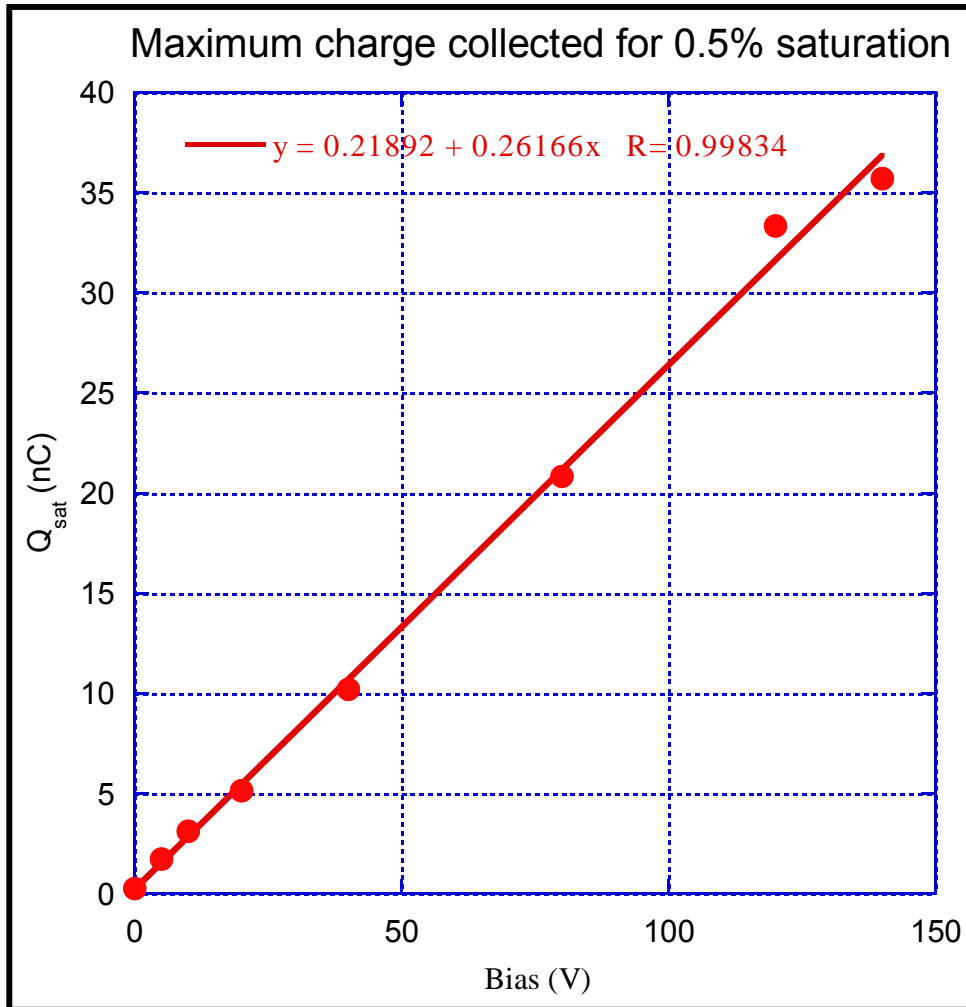


Silicon photodiode saturation

- Calibrations of EUV detectors are typically done with synchrotron radiation. (quasi-cw and low power)
- EUVL sources are pulsed with sub-microsecond durations and repetition rates up to 10 kHz with high peak powers.
- 532 nm has about the same penetration depth as Si at 13.5 nm and can be easily manipulated in the laboratory.
- Measurements of Si photodiode saturation behavior:
 - 10 W 532 nm cw laser with EO modulated output
 - pulse durations of 60 ns, 200 ns and 1000 ns
 - bias voltages of 5 V to 140 V
- Conclusions:
 - Saturation follows the relationship shown on the left.
 - Saturation is not pulse length dependent (below 1 μ s).
 - Results match previous work done.**
 - Q_{sat} can be defined which is the maximum amount of charge collected per pulse with less than 0.5% saturation loss.

***"Response of silicon photodiode to pulsed radiation," R. E. Vest and S. Grantham. Appl. Opt., Vol. 42, No. 25, 2003, pp.5054-63.

And "Linearity of P-N junction photodiodes under pulsed irradiation," R. Stuik, F. Bijkerk. Nuc. Inst & Meth A Vol: 489, No.1-3,2002 pp. 370-78

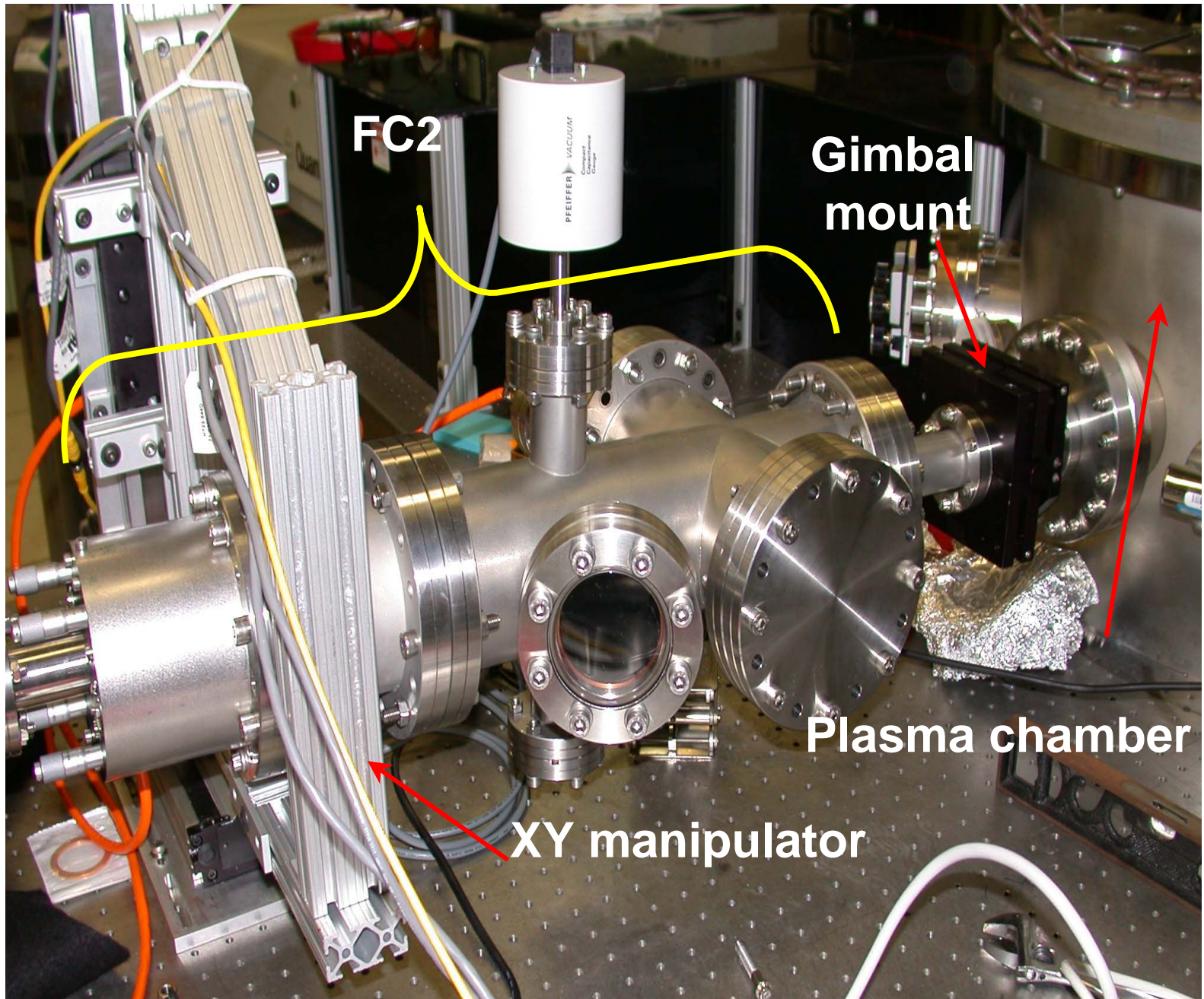


$$E_{pulse} = \frac{Q/R}{\left(1 - \frac{0.005 \cdot Q}{Q_{sat}}\right)}$$

R = detector responsivity
 Q = collected charge
 Q_{sat} = charge required for 0.5% saturation

LPP-based FC2[‡] calibration

- Xe-based LPP source
- Xe gas jet LPP-source with ~10 ns duration.
- MoSi mirror, two channel normalization scheme.
- 150 nJ per pulse in working standard channel.
- Zr-coated Working standard calibrated on SURF III EUV detector calibration facility.
- Results compared to predictions based on individual component calibrations.
- Saturation effects compensated using model developed with 532 nm measurements (see left).
- FC2 unsaturated ($Q < Q_{\text{sat}}$) under normal operating parameters (9V bias).
- Compensated results agree well with component calibrations.



FC2

**Gimbal
mount**

Plasma chamber

XY manipulator

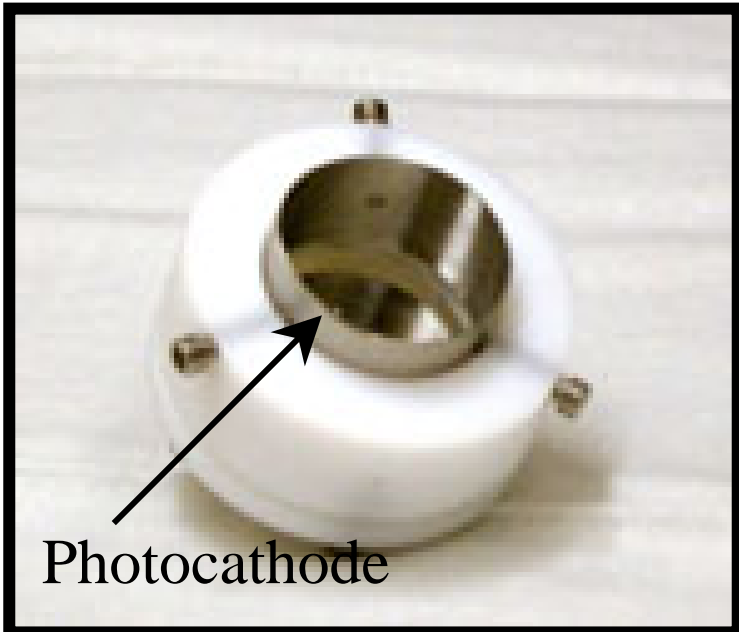
**Normal FC2
operating
parameters.**

FC2 filter Config.	Mean charge collected (nC)	Saturation factor	Predicted responsivity ratio	Measured responsivity ratio	Combined uncertainty ($\sigma_m + \sigma_p$)	Difference
FC2 (biased)	1.242	0.997	0.5134	0.5022	4.1 %	-2.2 %
FC2 + B (biased)	0.169	1.000	0.0685	0.0684	4.4 %	-0.2 %
FC2 + H (biased)	0.171	1.000	0.0677	0.0691	7.0 %	+2.1 %
FC2	1.205	0.978	0.5039	0.4872	4.7 %	-3.3 %
FC2 + G	0.281	0.995	0.1113	0.1135	4.8 %	+2.0 %
FC2 + B	0.168	0.997	0.0683	0.0679	4.5 %	-0.6 %
FC2 + H	0.169	0.997	0.0675	0.0685	4.5 %	+1.6 %
WS	2.473	0.956	-	0.7076	-	-

Al₂O₃ photoemissive detectors for EUVL source monitoring

- Al₂O₃ photoemissive detectors are fast (rise times ~1 ns) with low noise but lower sensitivity compared to Si photodiode (~1/10th).
- High source power may permit their use in EUVL.
- Blind to wavelengths longer than 130 nm.
- New design incorporates filter-type anode to reduce EMI and plasma electron signal.
- New design significantly reduces EMI and has fast rise and fall time (see below).

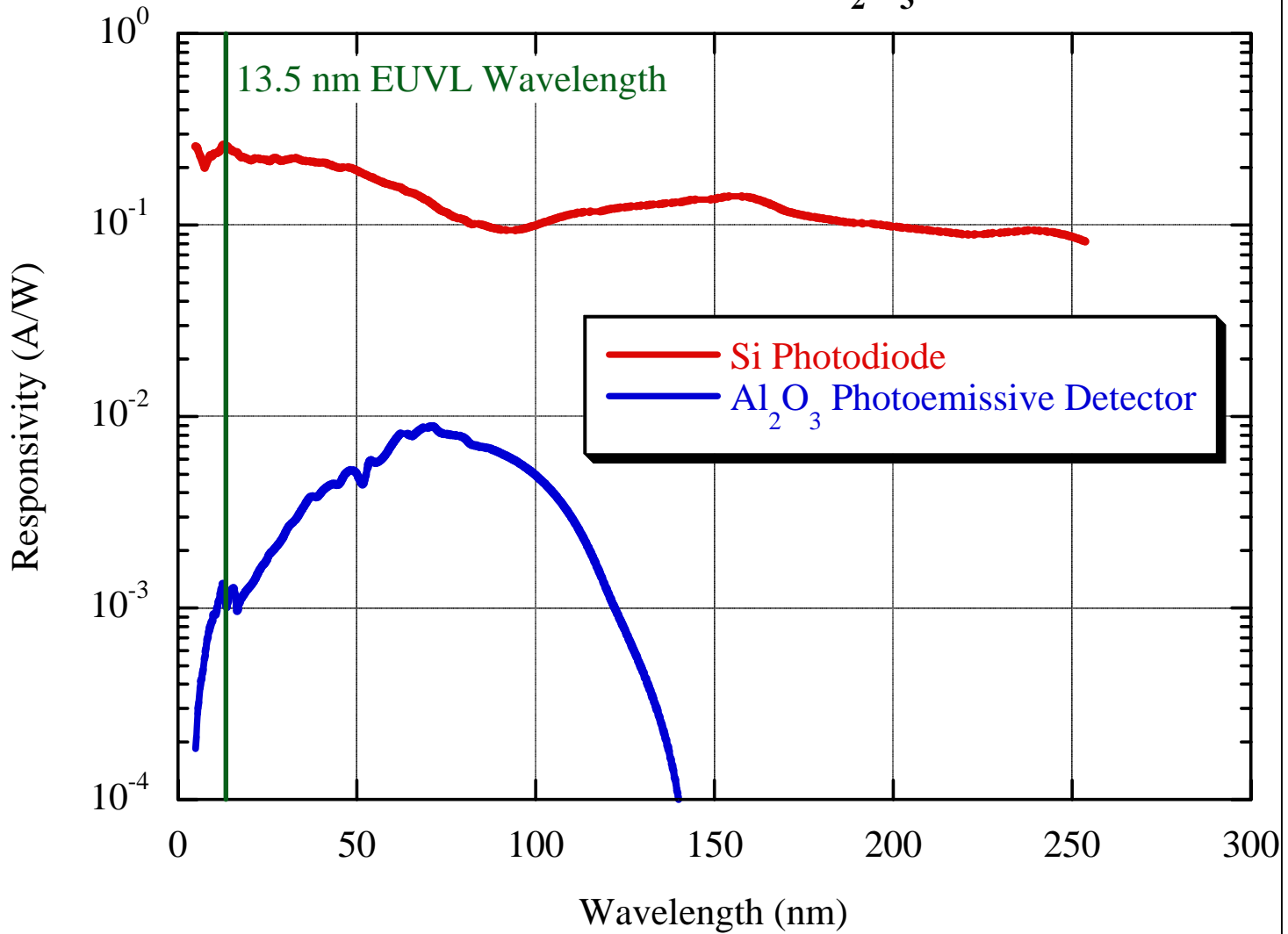
CW design



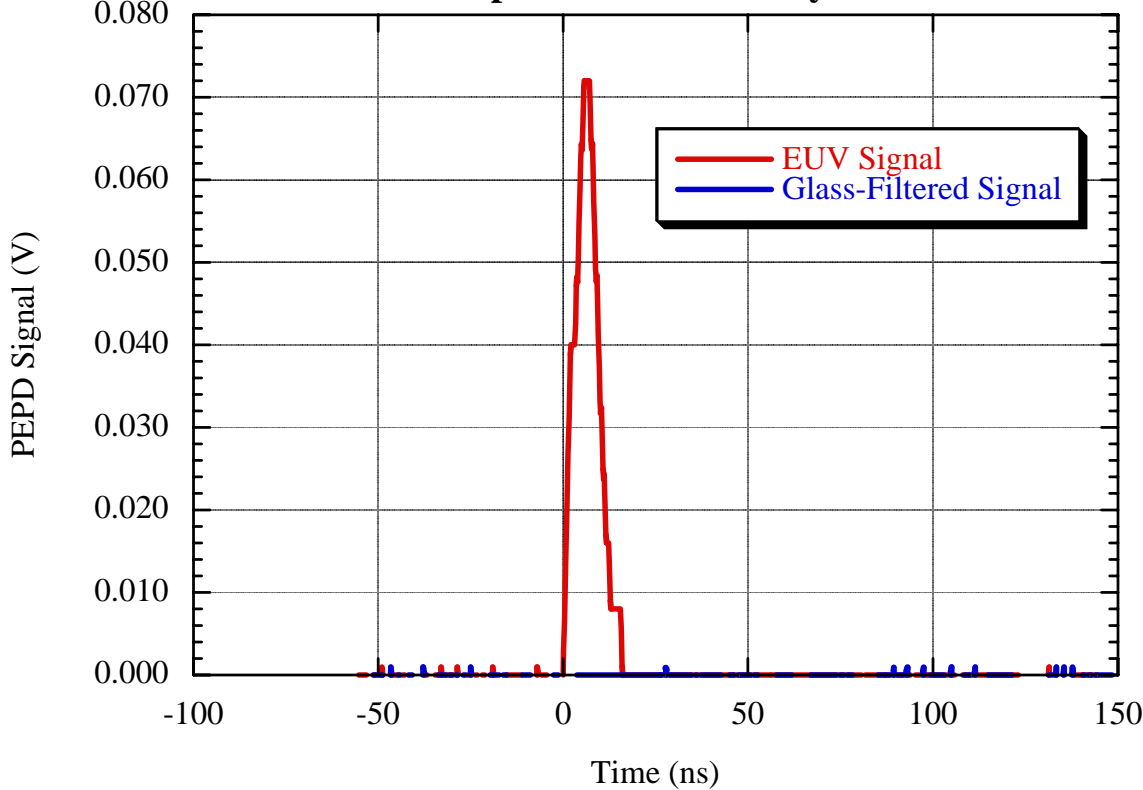
Pulsed design



Typical Responsivity of Si and Al₂O₃ EUV Detectors



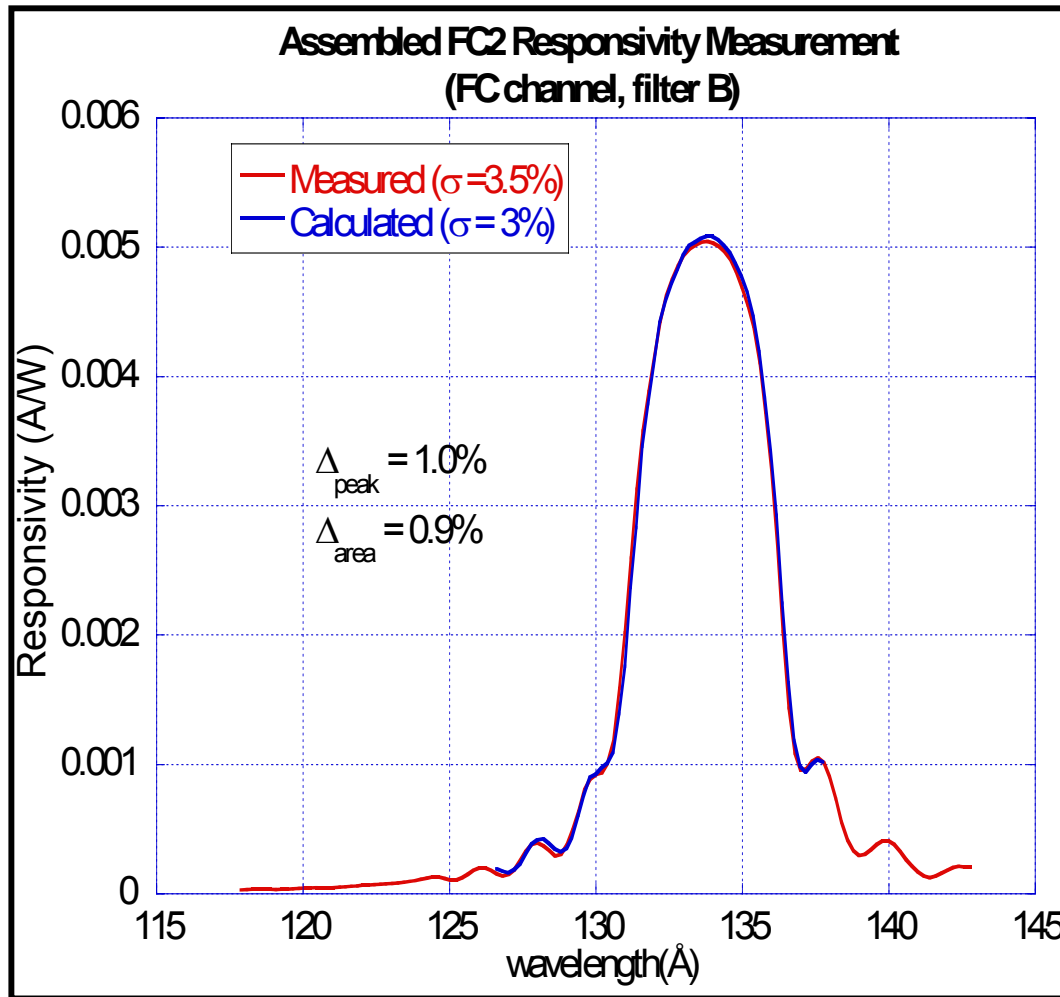
PEPD Response With Multilayer Mirror



Measurements of assembled EUV instrumentation on SURF III

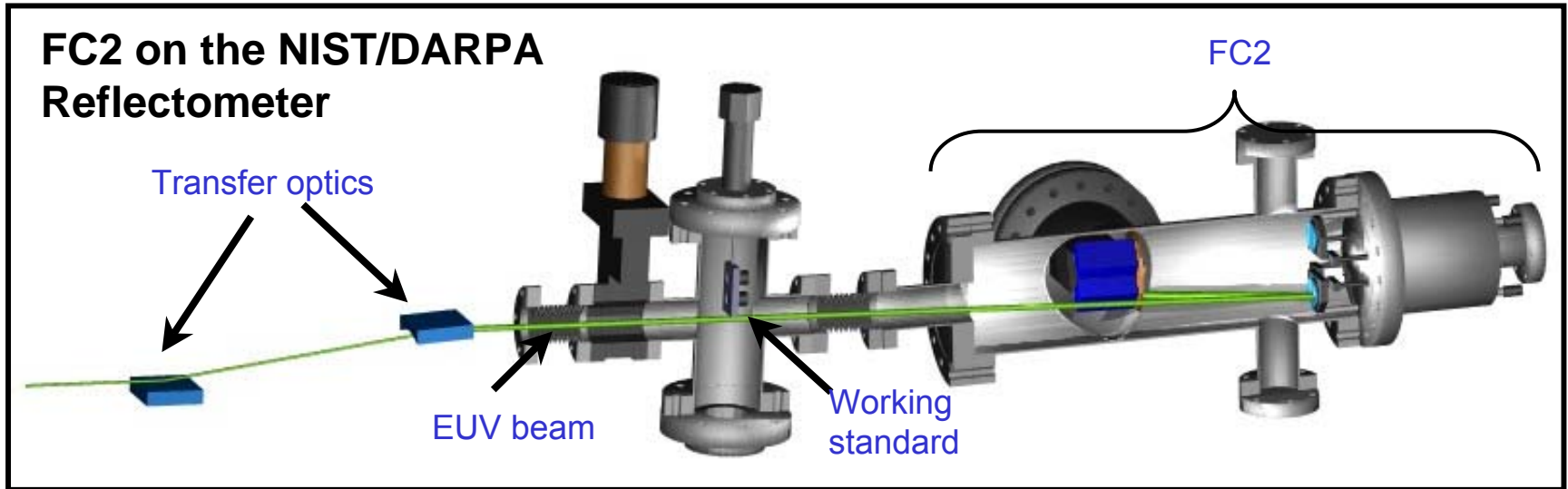
CW assembled FC2 calibration

- Calibration runs completed 01/2004
- Assembled FC2 unit attached to NIST/DARPA reflectometer as endstation.
- Individual components calibrated.
- Individual component data used to calculate response and compared to assembled FC2 measurement.
- Measurements made for several filter and mirror configurations.
- Measurement uncertainty improvement expected from pending beamline modifications and upgrades



Note: The measured peak is shifted due to the high angle of incidence necessary for the NIST measurement, under normal use the FC2's responsivity is nominally at 135Å.

Measurements of assembled EUV instrumentation on SURF III

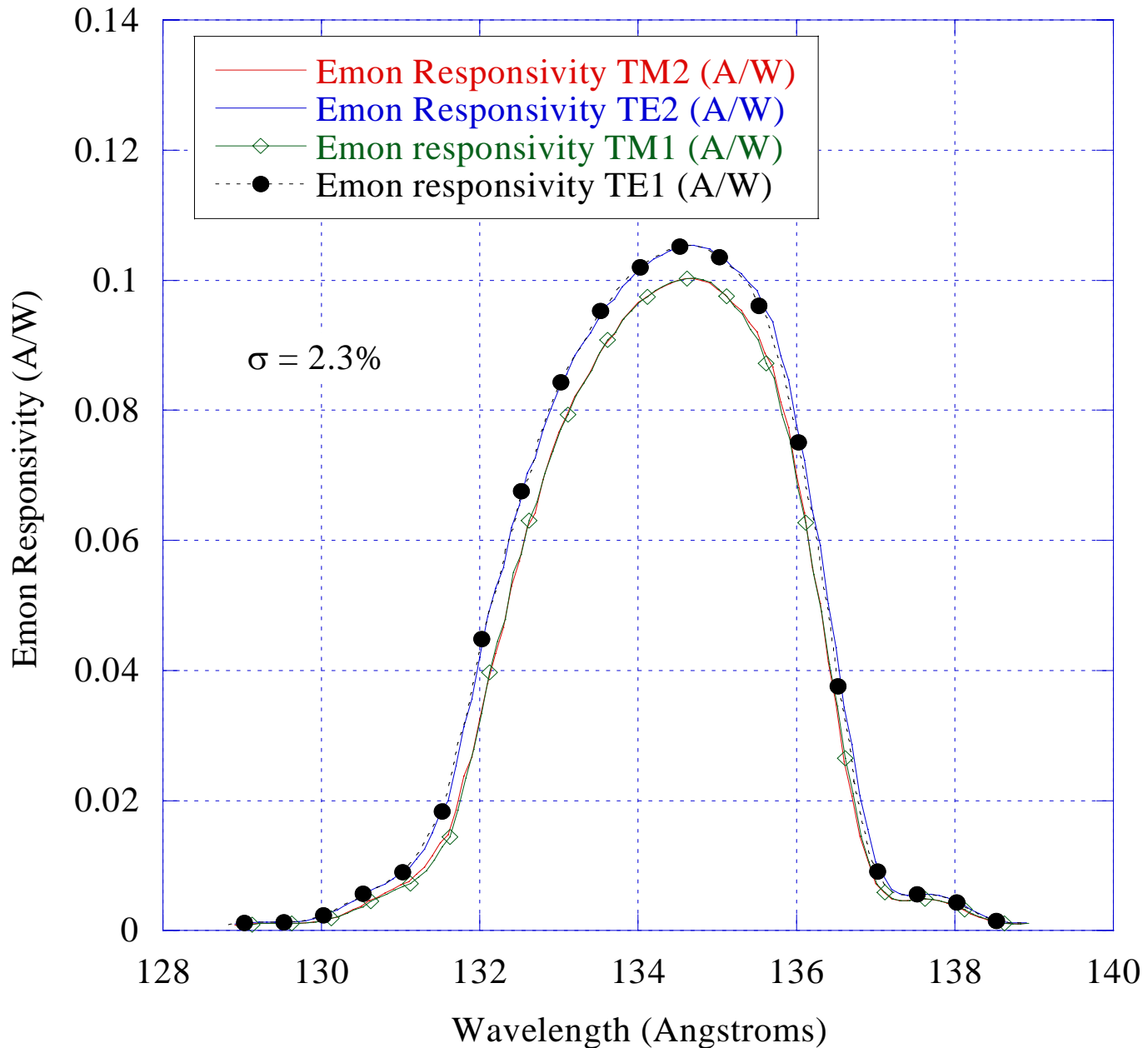


Measurements of assembled EUV instrumentation on SURF III

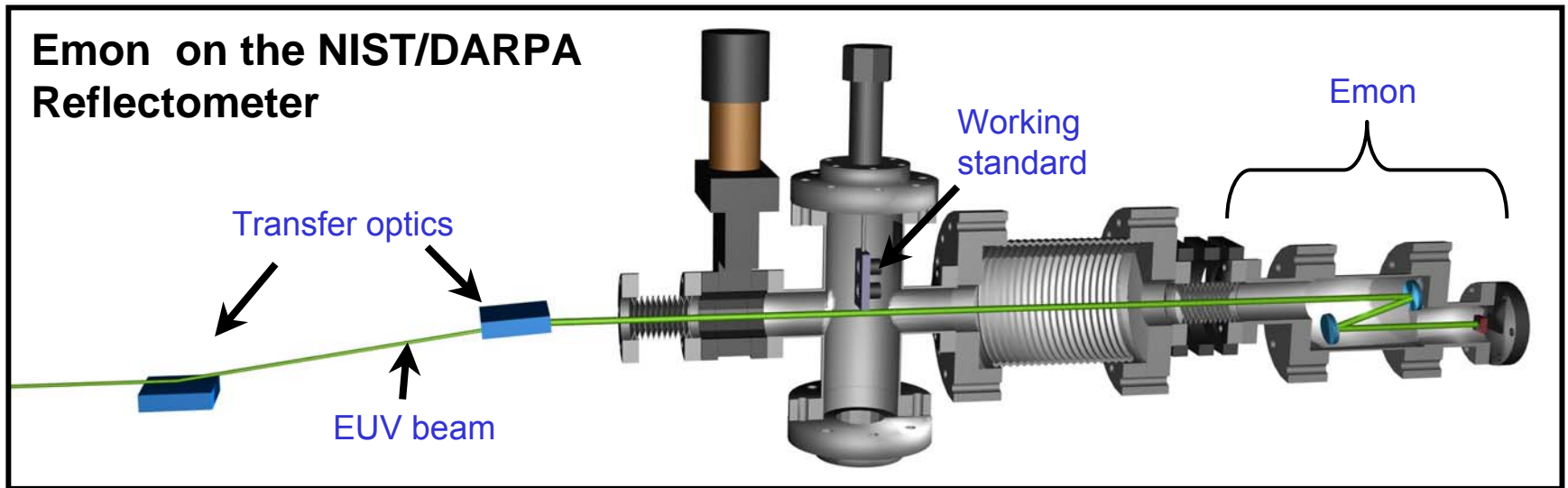
CW assembled Emon calibration

- Calibration runs completed 07/2004
- Emon unit attached to NIST/DARPA reflectometer as endstation.
- Responsivity measured with both TE and TM polarization configurations.
- Due to off-axis multilayer reflections (10° angles of incidence) that are dependent on the polarization. Both measurements necessary to determine un-polarized response.
- Raw data modeling done to determine monochromator effects on the measurement to provide a more accurate calibration.
- Separate measurement of Emon Zr filter also made.

Emon calibration based on Raw data



Measurements of assembled EUV instrumentation on SURF III



Future plans:

- **Upgrade of NIST/DARPA reflectometer facility's monochromator to begin Spring 2005.**
- **Expand NIST/DARPA reflectometer facility's endstation capability to include CCDs and spectrographs.**
- **Expansion of pulsed detector characterization research to include illumination spot size and sample-to-sample variability.**
- **Upgrade EUV detector calibration beamline to include additional filters for improved higher-order and out-of-band radiation signal rejection.**

Summary:

NIST over the past year has conducted a wide variety of measurements and calibrations to support the EUVL source-development community. These included the calibration of individual components for radiometric instruments and the calibration of assembled radiometry instrumentation. NIST has also expanded its capabilities to characterize detectors under pulsed illumination conditions similar to those present in EUVL and to calibrate instruments with at-wavelength pulsed illumination. NIST will continue to expand its EUV calibration program to further meet the needs of the EUVL community.