NRL Work at NSLS X24C and Transition to NSLS-II

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X24C research focus:

Scientific research and development:

- **Extreme ultraviolet and soft x-ray regions (up to 1 keV).**
- **Optical properties of materials, multilayer reflective coatings, material interface science, diffraction gratings and zone plates, transmissive filters, electronic detector calibration, radiation damage.**
- **Application to NRL, NASA, and NOAA spaceflight instrumentation.**

NRL has budgeted capital equipment funds in FY11 for the transfer of X24C capabilities to NSLS-II with enhancements (coverage to 10 keV and higher resolution).

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X24C Key Personnel

X24C

Position	Name	Institution
Spokesperson	Jack Rife	NRL
PRT management, scheduling	John Seely	NRL
Beamline Scientist, Safety, Training, Local Contact	Benjawan Kjornrattanawanich	USRA
Technical Staff, Local Contact	Johnny Kirkland	SFA Inc.
Technical Staff	Glenn Holland	SFA Inc.

We are looking to form a broad-based BAT for NSLS-II.
Please contact john.seely@nrl.navy.mil

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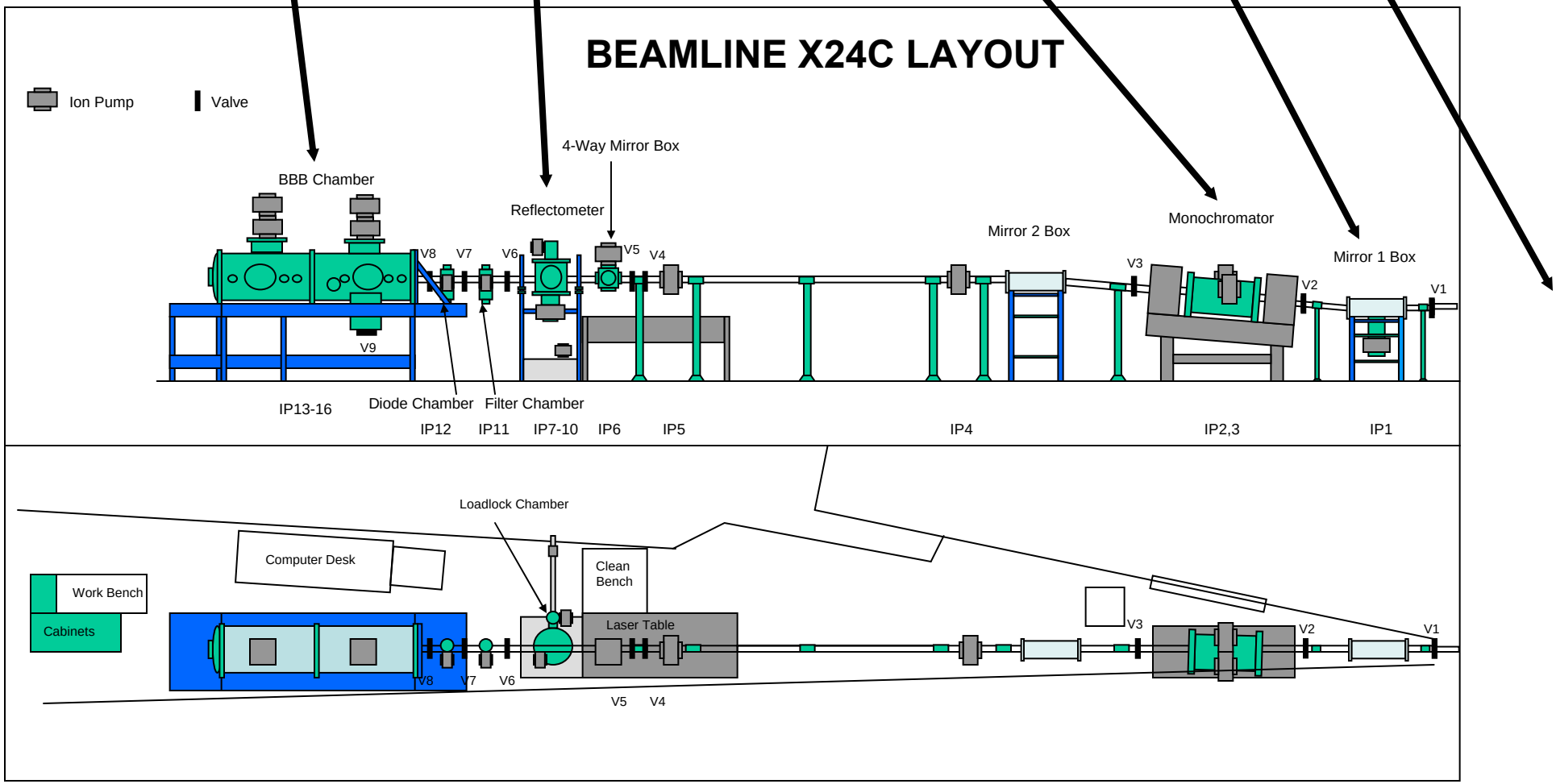
X24C Layout

X24C

Calibration Chamber Reflectometer Monochromator(3.4°-80°) M1(2°) Bend Magnet



X24C Monochromator

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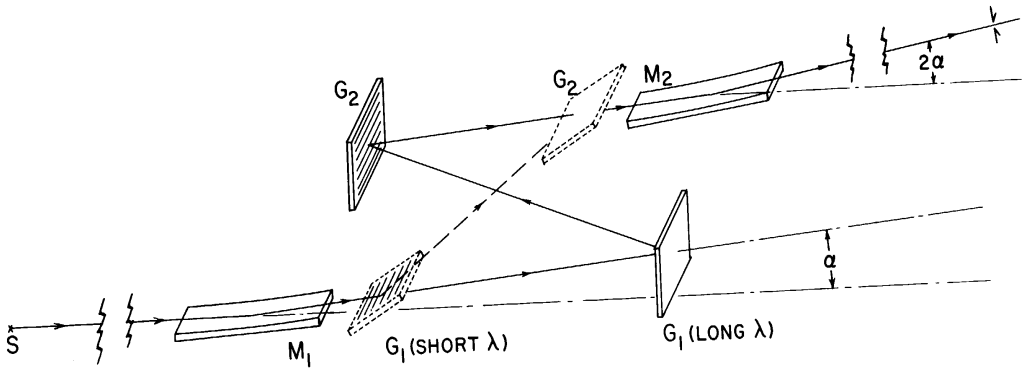
- Two elements (e.g. grating and mirror) are precisely translated and rotated by computer control while maintaining fixed entrance and exit slits.
- Gratings are selected without breaking vacuum and cover from 1 keV through the visible.
- 10^8 to 10^{12} photons/sec/0.1% bandpass peaking at ~ 100 eV, resolution up to 1000.
- 2^o grazing mirrors M1 and M2 were upgraded in 1999 with NRL capital equipment funds.



The radiation is 90% polarized with the electric field vector in the plane of the storage ring. This permits the study of the polarization properties of EUV/x-ray optics. The polarization properties impact the science that can be accomplished with solar and astrophysical spaceflight instruments. X24C is the world's leading beamline for these studies.

New mono optics (and new M1 and M2) will extend coverage to 10 keV at NSLS-II.

X24C Sample Chambers

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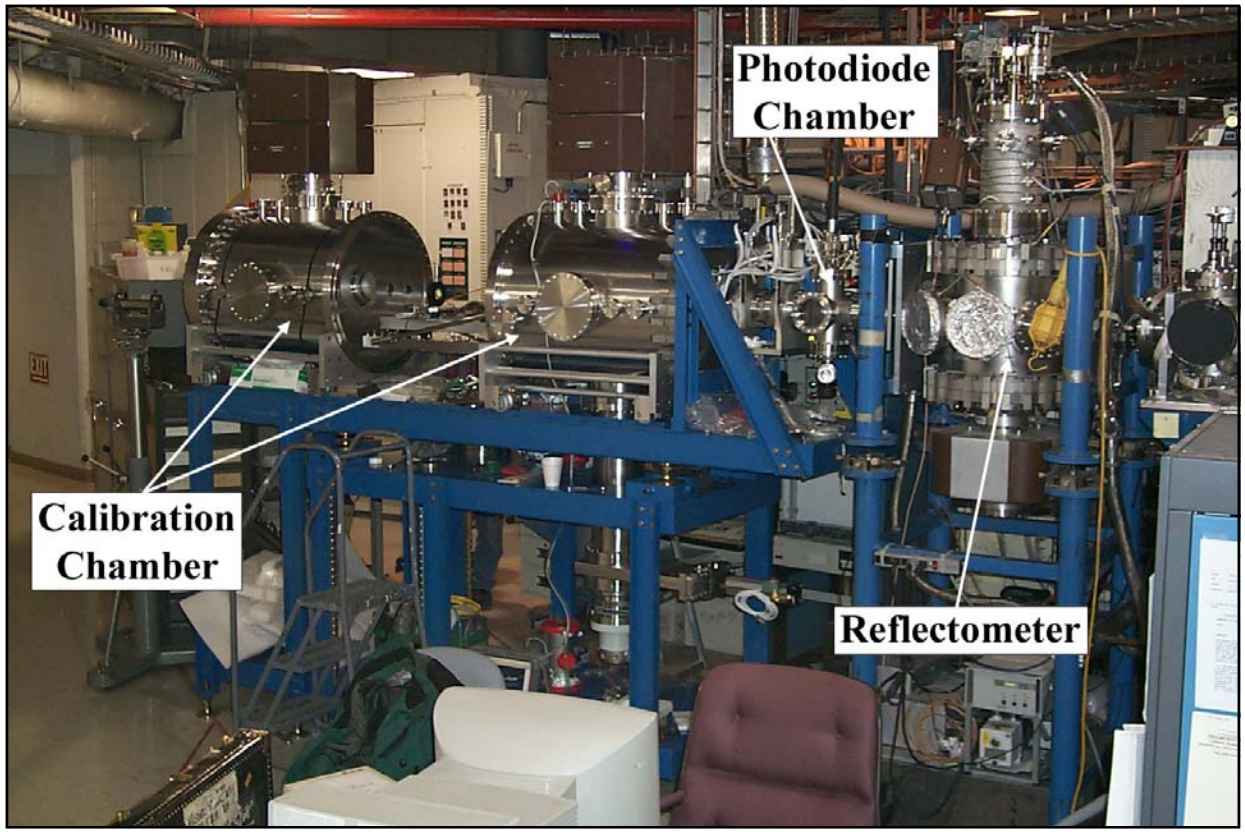
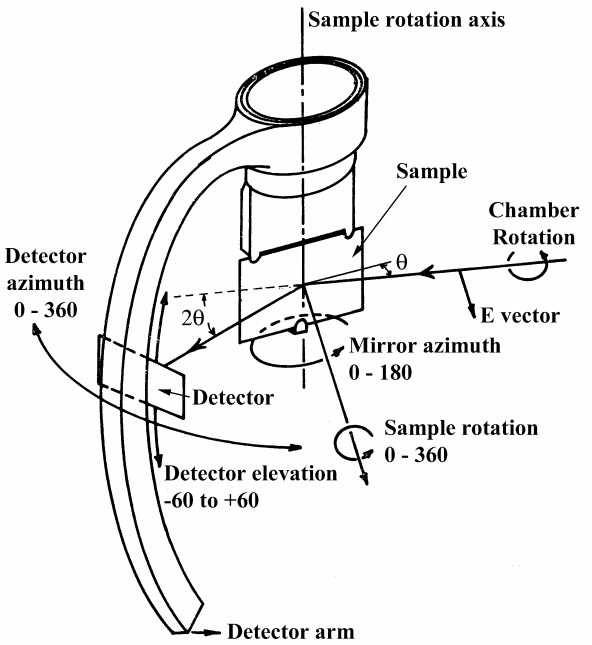
- UHV reflectometer is used for small sample measurements:
  - Can be rotated about the incident beam for S and P polarization studies.
  - High reflectance multilayer interference coatings on mirror/grating substrates.
  - High efficiency diffraction gratings (reflection and transmission gratings).
- Photodiode chamber for detector sensitivity and radiation damage studies.
- Large calibration chamber for large optics and spaceflight instrument components.



Computer controlled θ-2θ reflectometer:



Large Calibration Chamber

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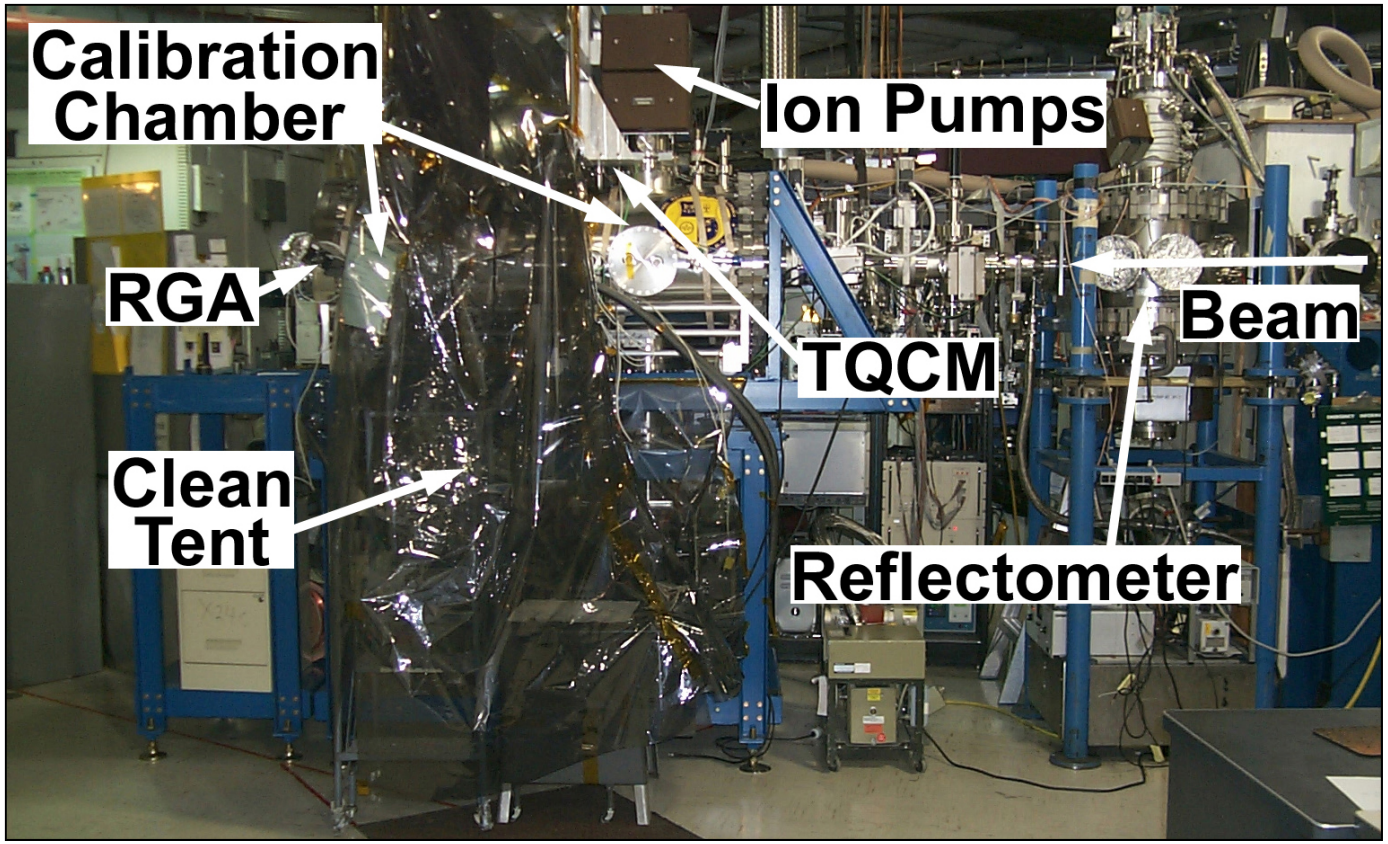
Research, development, and calibration of spaceflight optics and detectors:

- **Large (up to 1 m long) optics, detectors, instrument components can be calibrated.**
- **Clean vacuum conditions (RGA and TQCM monitors).**
- **Isolated from the UHV reflectometer and beamline by differentially pumped filters.**
- **Sample and detector mounts/goniometers with computer-controlled, precision translational and angular motions.**



Projects and Collaborations

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•NRL/ONR: High efficiency multilayer-coated EUV gratings

•NASA: High-resolution EUV spectrometer for the Solar-B mission →

Normal-incidence multilayer grating covering 17-30 nm wavelengths.

ISAS/Japan, Mullard Space Lab/England; Reflective X-Ray Optics

•NASA: λ<3 nm multilayers and interface engineering <0.1 nm

Reflective X-Ray Optics (David Windt)

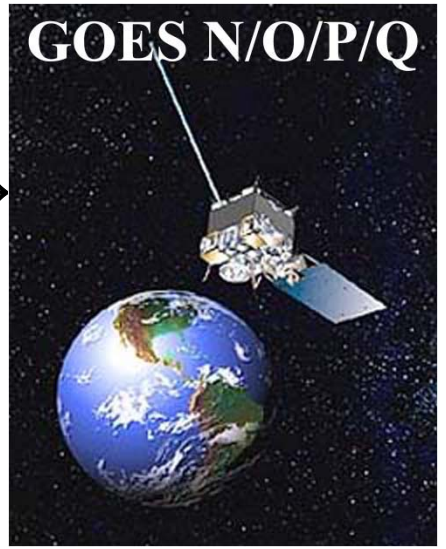
•NASA: Optical properties of materials in the extreme ultraviolet

Reflective X-Ray Optics, Lebedev Institute/Russia

•NASA/Goddard: Multilayer telescope/grating absolute calibrations

Goddard Space Flight Center

•NOAA: Solar spectrometer calibrations for the GOES N/O/P/Q satellites →



Boeing Aerospace/Seattle, Assurance Technology Corp/Boston,

International Radiation Detectors Inc/Los Angeles

•CCD Absolute Calibrations in the extreme ultraviolet region

MIT Lincoln Lab, Mullard Space Lab/England, NASA

•DOE: Time-resolved soft x-ray flux from laser-produced plasmas

Silicon photodiode sensors, absolute calibrations, subnanosec time response.

NRL Plasma Physics Division, NIKE laser

Extreme Ultraviolet Imaging Spectrometer (EIS)

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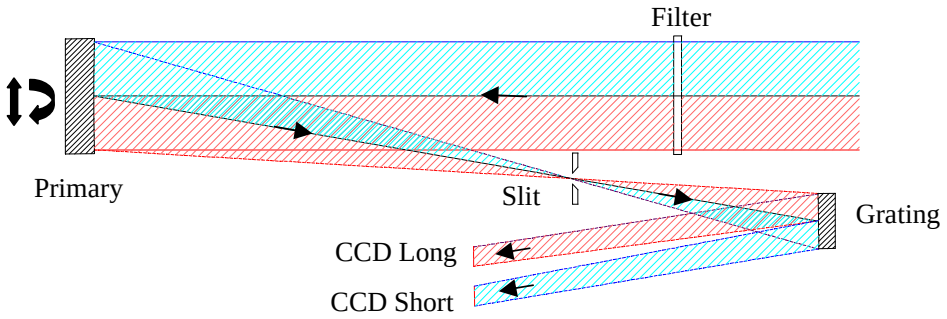
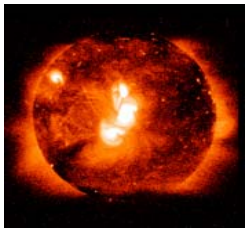
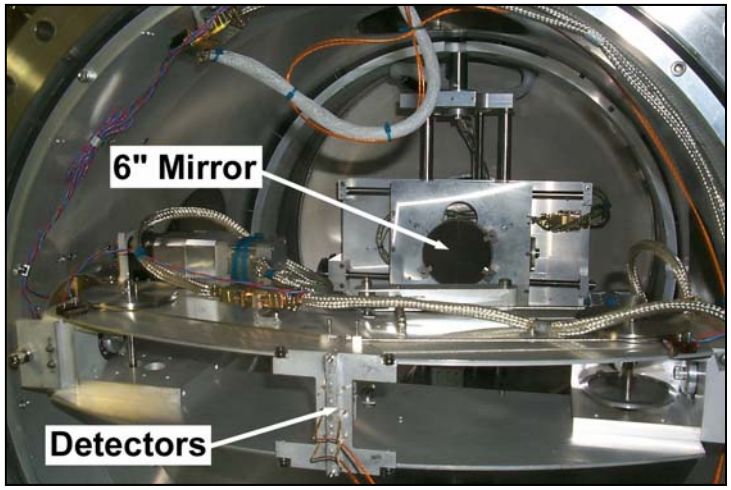
First satellite spectrometer with a multilayer grating:

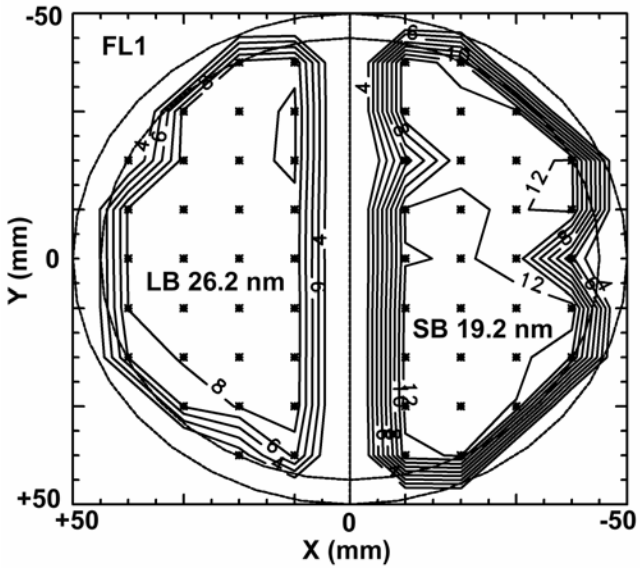
- **Built by NRL, Mullard Space Lab/England, GSFC, ISAS/Japan, launched in 2006.**
- **Multilayer coatings cover 17-21 nm and 23-29 nm.**
- **Designed for the study of solar regions: corona, active regions, flares.**
- **Measurement of temperatures, densities, emission measure, Doppler shifts.**





Sun





Characterization of Xradia Zone Plate (1)

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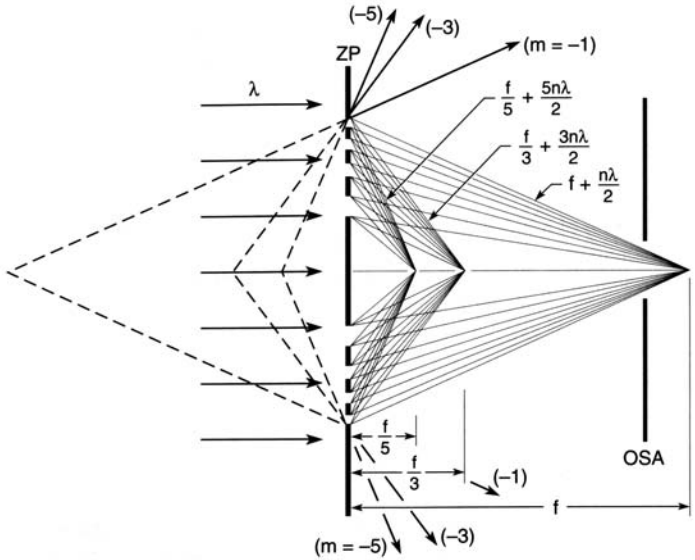
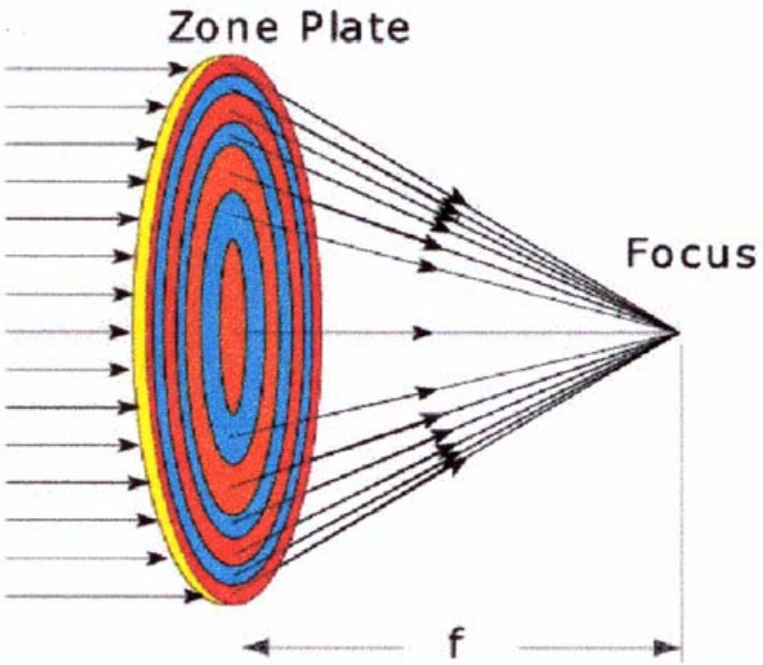
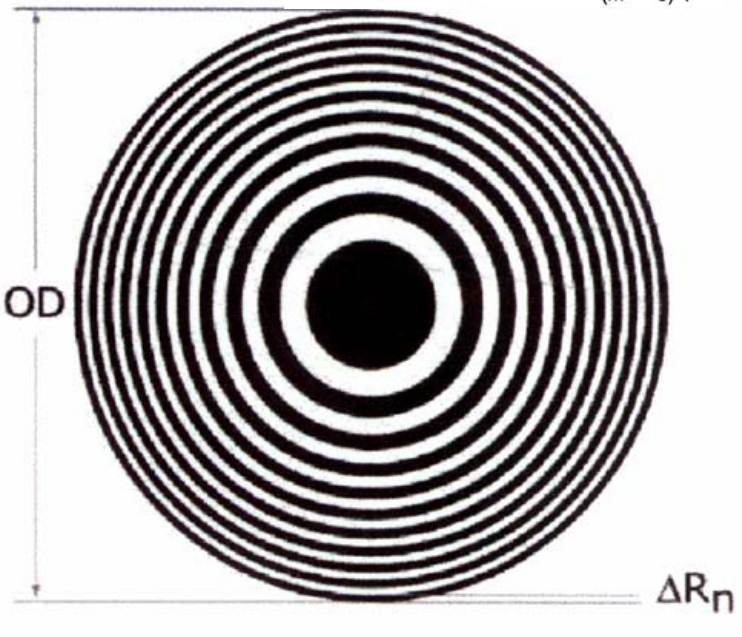
- Fresnel zone plate is composed of open and opaque circular zones designed to focus the +1 diffraction order on the axis with focal length f~1/λ.
- The –N orders are diverging, and the N=even orders ideally have zero efficiency.







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Characterization of Xradia Zone Plate (2)

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Important experimental parameters:

- **2 mm OD, 180 nm thick gold.**
- **1 mm central stop, 0.5 mm thick ss.**
- **Si_3N_4 support membrane, 2.5x2.5 mm^2 area, 100 nm thick.**
- **$f = OD\ \Delta R_n/N\lambda = 300\ mm/N\lambda[nm]$ where N=order number.**

Zone Plate Parameters:

Outer Diameter	µm	2000
Inner Diameter (no zones)	µm	1000
Outermost Zone Width	nm	150
Zone Material		Electroplated Gold
Zone Height	nm	180 +/- 10%
Number Of Zones[2]		3330
Suggested Energy Range[3]	keV	0.13-1.4
Theoretical Max. Diffraction Efficiency[1]	%	15 (@ 1.1 keV)
Support Membrane Material		Si_3N_4
Support Membrane Thickness	µm	0.1
Support Membrane Size	mm	2.5 x 2.5
Support Silicon Frame Size	mm	6 x 6
Central Stop Diameter[4]	µm	1000
Central Stop Height / Material	µm	500/stainless steel

[1] The guaranteed focusing efficiency for condenser zone plates is 50% of the theoretically calculated value.
[2] Number of fabricated rings calculated for a full zone plate (no missing inner zones).
[3] Energy range for which the theoretical efficiency is greater 10%.
[4] The stop for the condenser is a EDM-cut stainless steel plate.

Characterization of Xradia Zone Plate (3)

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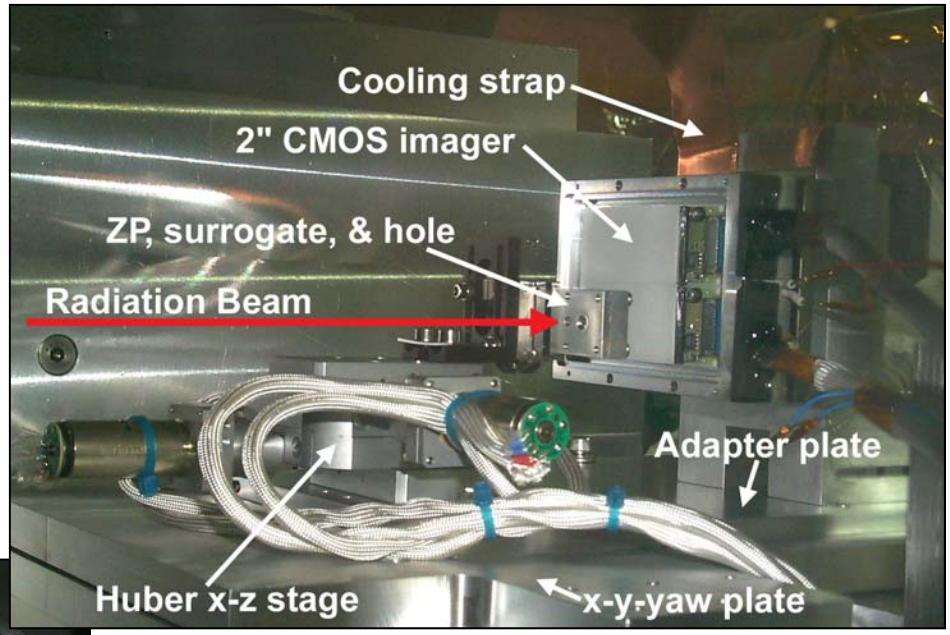
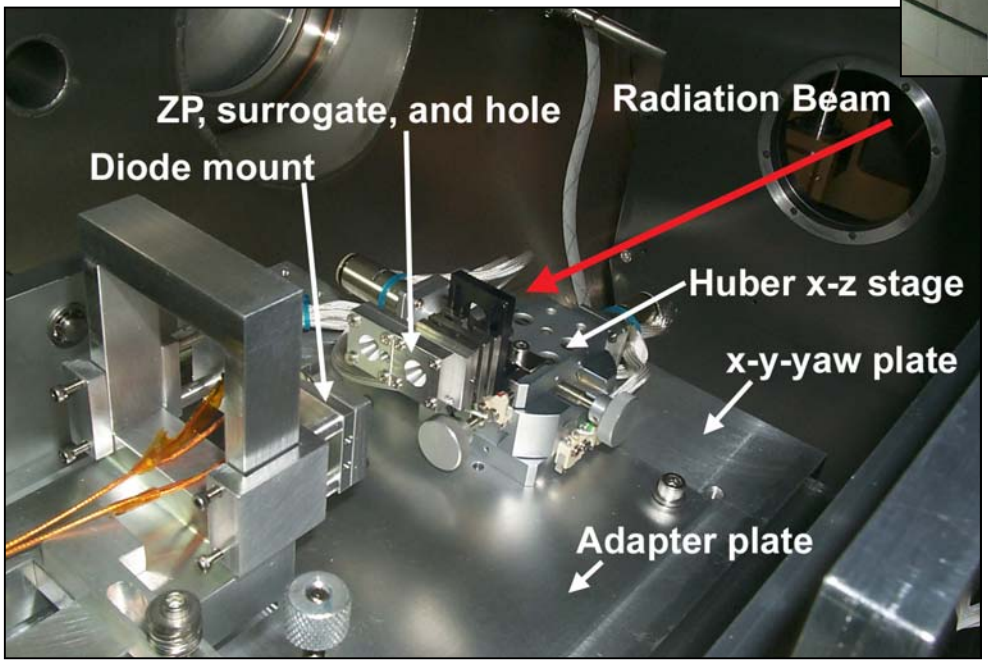
Front view of the CMOS imager:



Back view of the diode mount:



Motions controlled from outside

- **Calibration chamber x-y-yaw plate:**
  - **Center ZP or surrogate in beam.**
  - **Rotate ZP off-axis.**
- **Huber x-z relative to x-y-yaw plate:**
  - **Change ZP-detector distance.**
  - **Move ZP or surrogate into beam.**
- **Detector x-y relative to ZP:**
  - **Center detector behind ZP.**

Characterization of Xradia Zone Plate (4)

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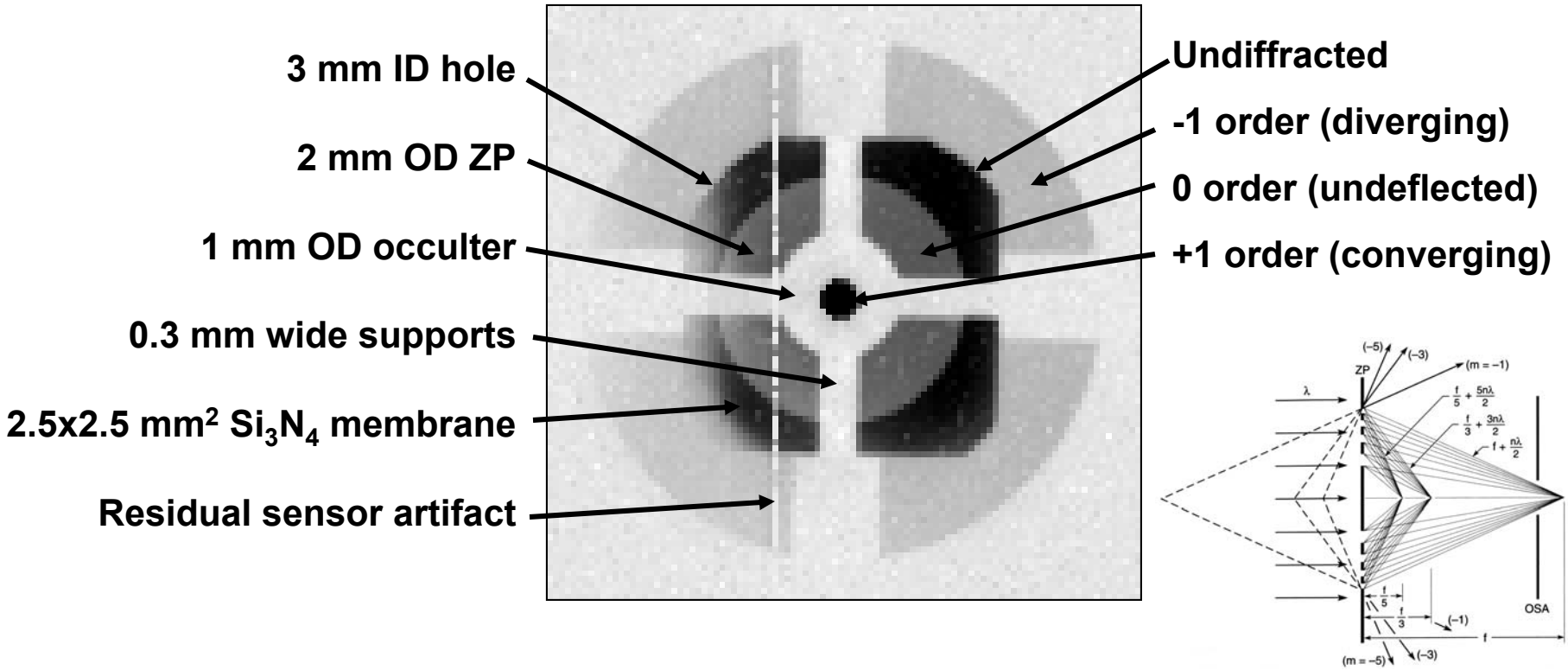
- Apertures upstream of the ZP define the radiation beam diameter/divergence.
- The beam divergence was ±5 mrad (small, resulting in sharp shadows).
- The beam through the 2 mm aperture overfilled the ZP and revealed features.
- Image has 100x100 pixels (48 μm), 4.8x4.8 mm^2 size (13.5 nm wavelength):



Photodiode Responsivity

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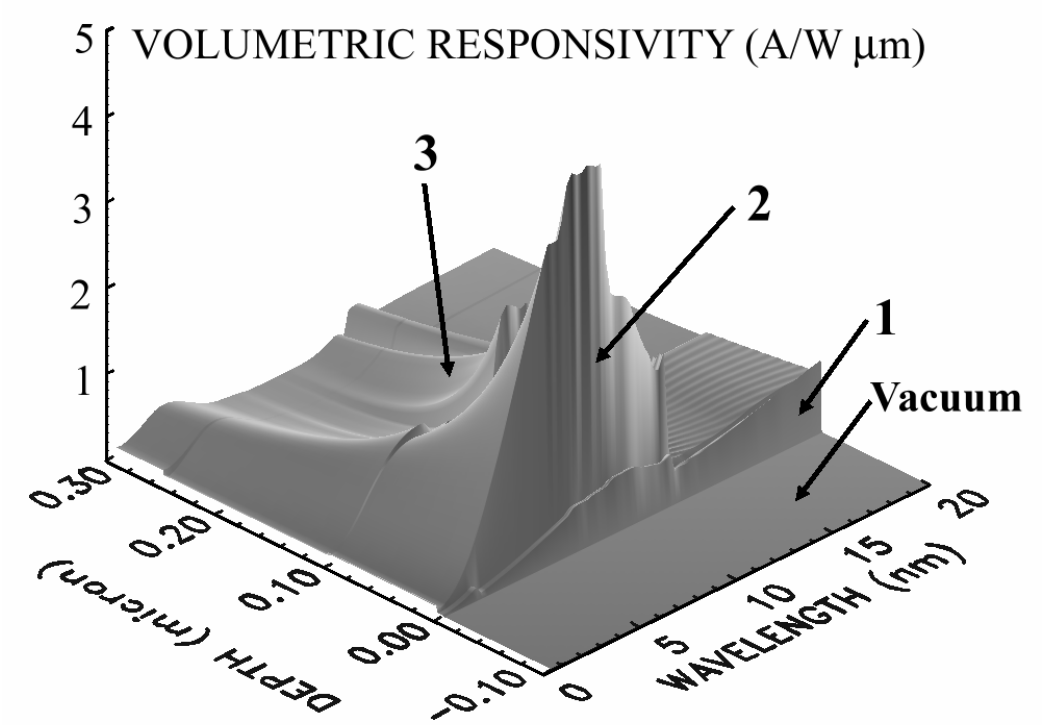
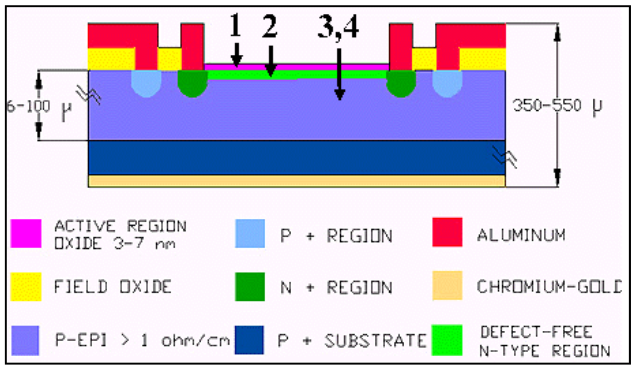
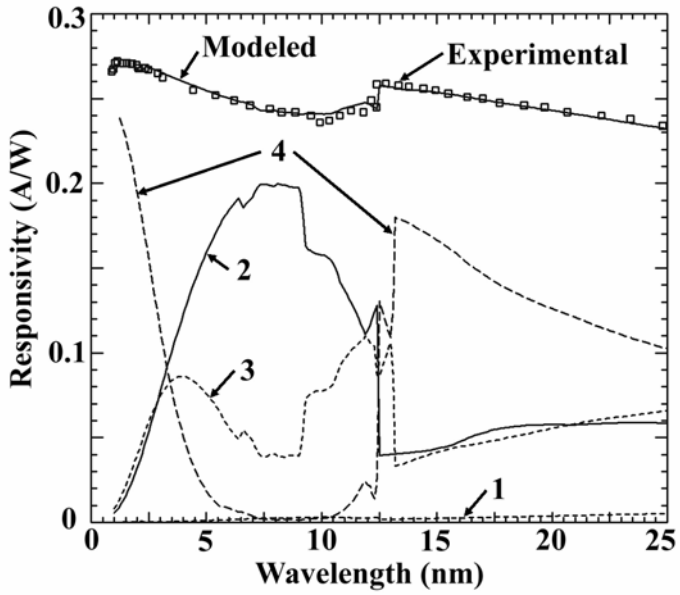
- Optical models for the responsivities of EUV/x-ray photodiodes (Si, SiC).
- Multiple-layer coatings provide EUV bandpasses, polarization sensitivity, and visible light blocking.
- Adopted for GOES EUV spectrometers and for NRL laboratory x-ray measurements.
- Calibration model for an uncoated Si photodiode:

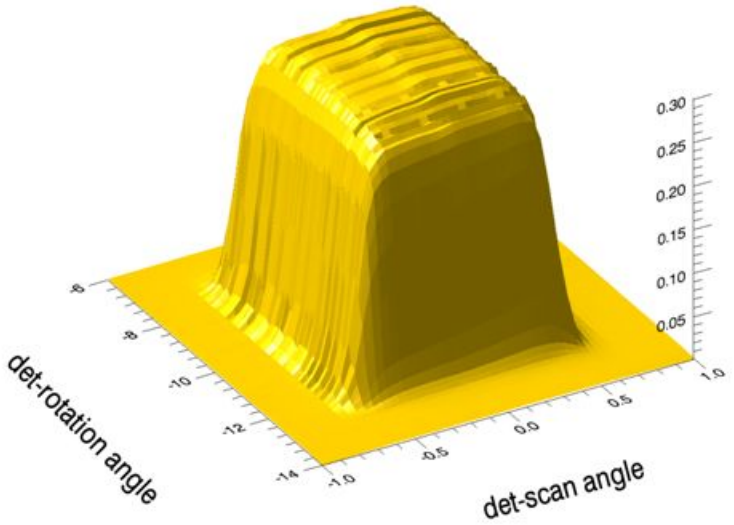




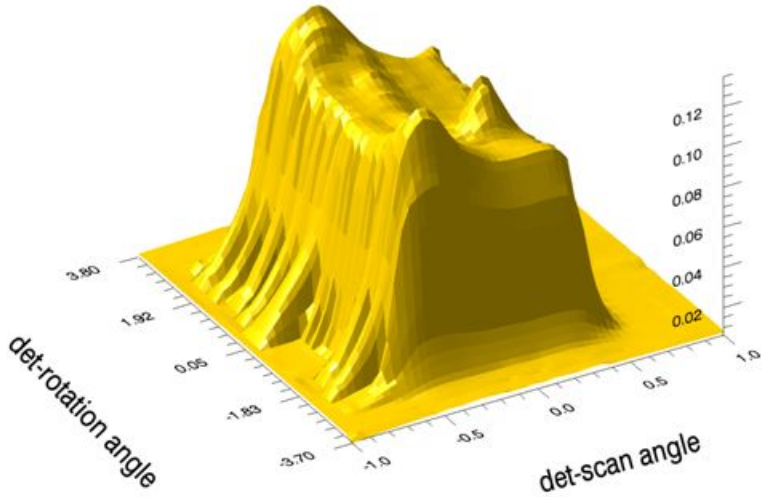


Radiation Damaged Photodiodes

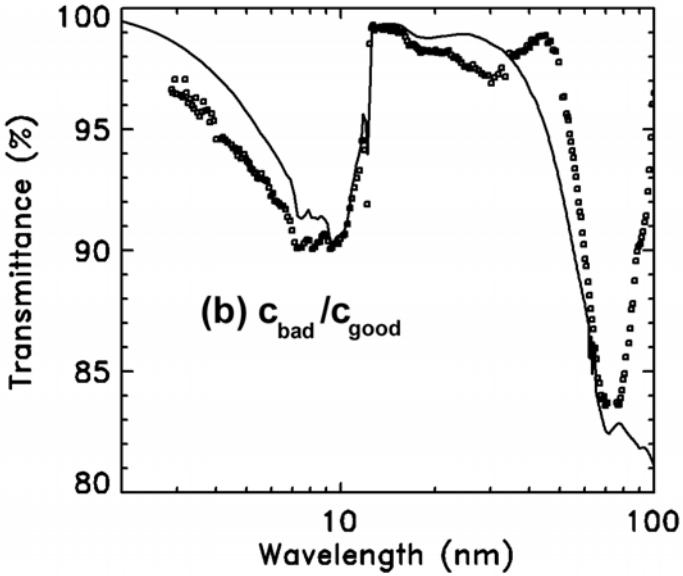
Pristine AXUV100G (1 cm square)



Radiation Damaged AXUV100G



Radiation damaged is modeled by reduced charge collection efficiency in the topmost Si layer.



Pulsed Photodiode Responsivity

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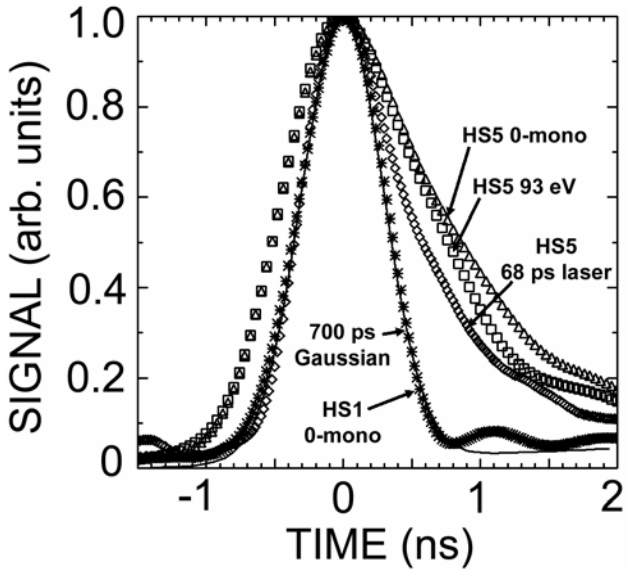
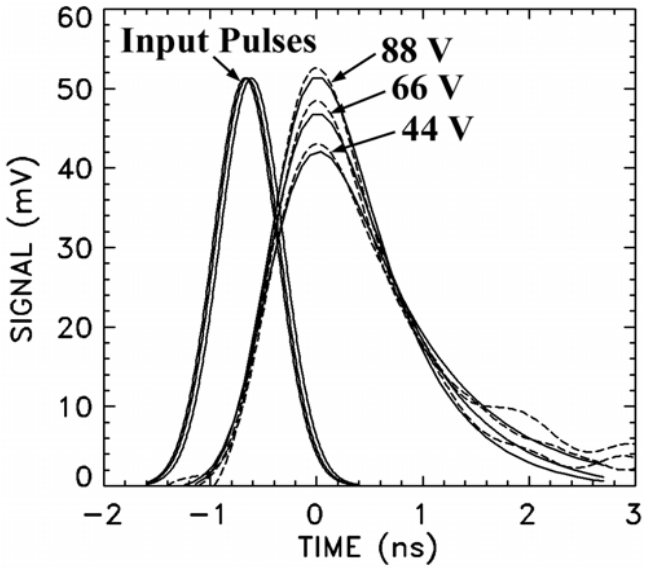
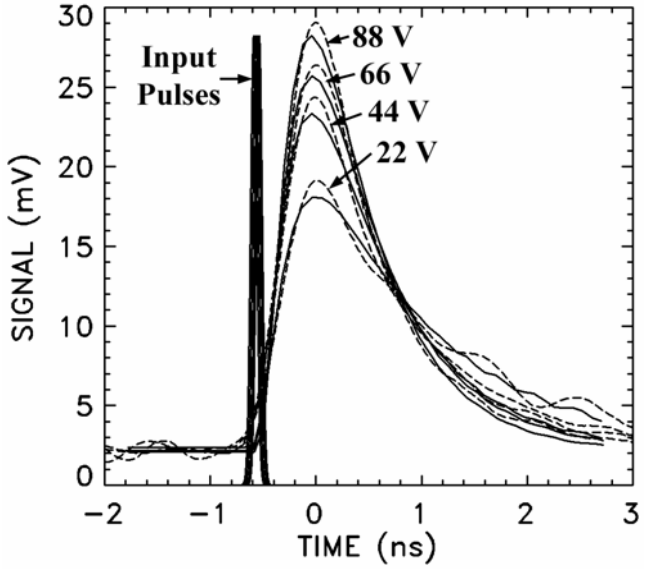
Number	Type	Area (mm^2)	Aperture Diameter (mm)
1	AXUV-HS5	1 x 1	0.8
2	AXUV-HS5	1 x 1	0.4
3	AXUV-HS1	0.22 x 0.22	0.15
4	AXUV-100G	10 x 10	0.8



HS5: 700 ps NSLS single bunch



68 ps laser



Inferred Capacitance