X24C Beamline
National Synchrotron Light Source

John F. Seely, Naval Research Laboratory
James C. Bremer, Research Support Instruments, Inc

Solar EUV Workshop

LASP, Boulder, Co: Oct. 25-27, 2011

Supported by NASA project NNH09AK121
"Ultra-Stable Extreme Ultraviolet Solar Monitor using Zone Plates"

NRL Space Science Division

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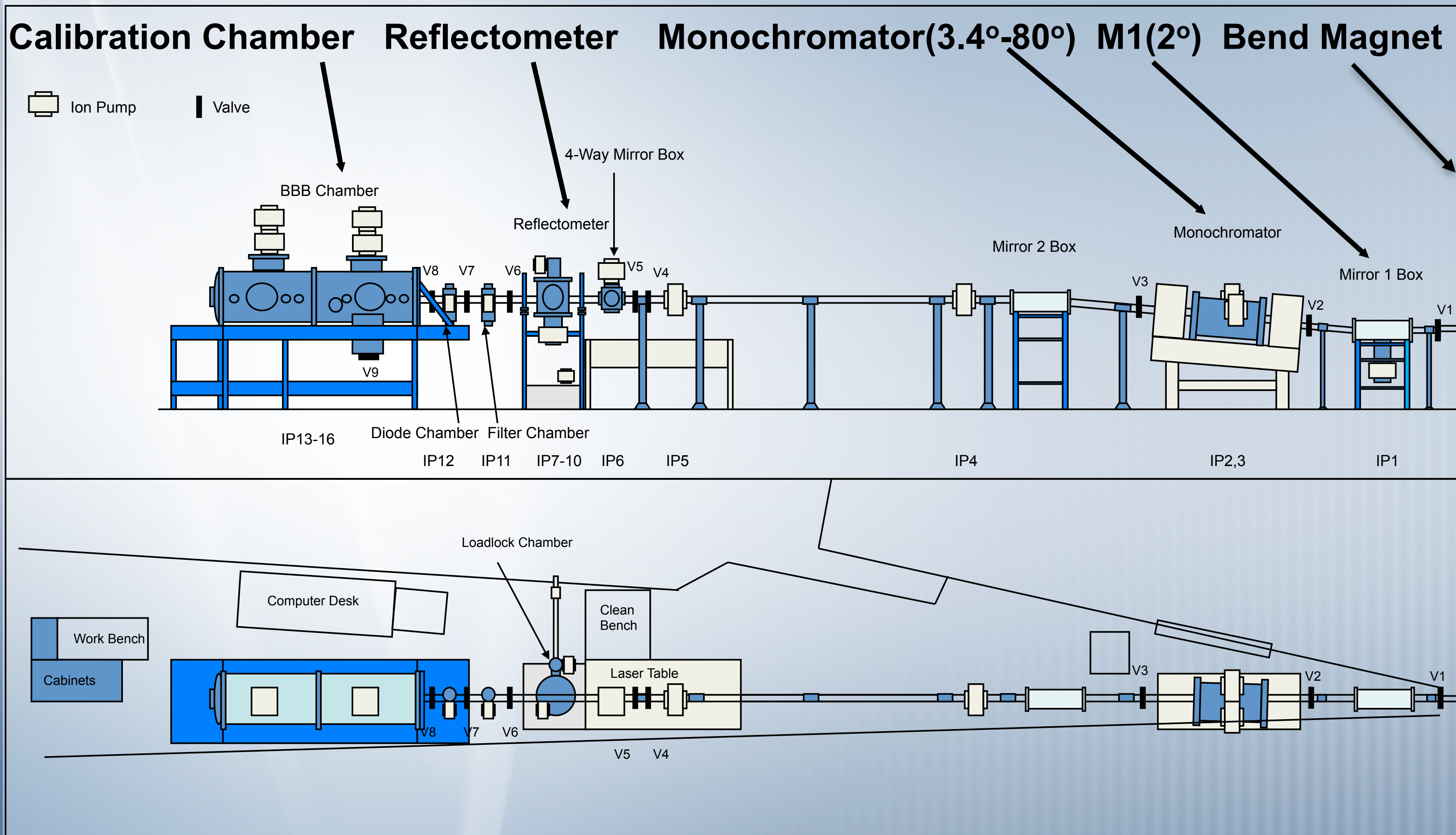
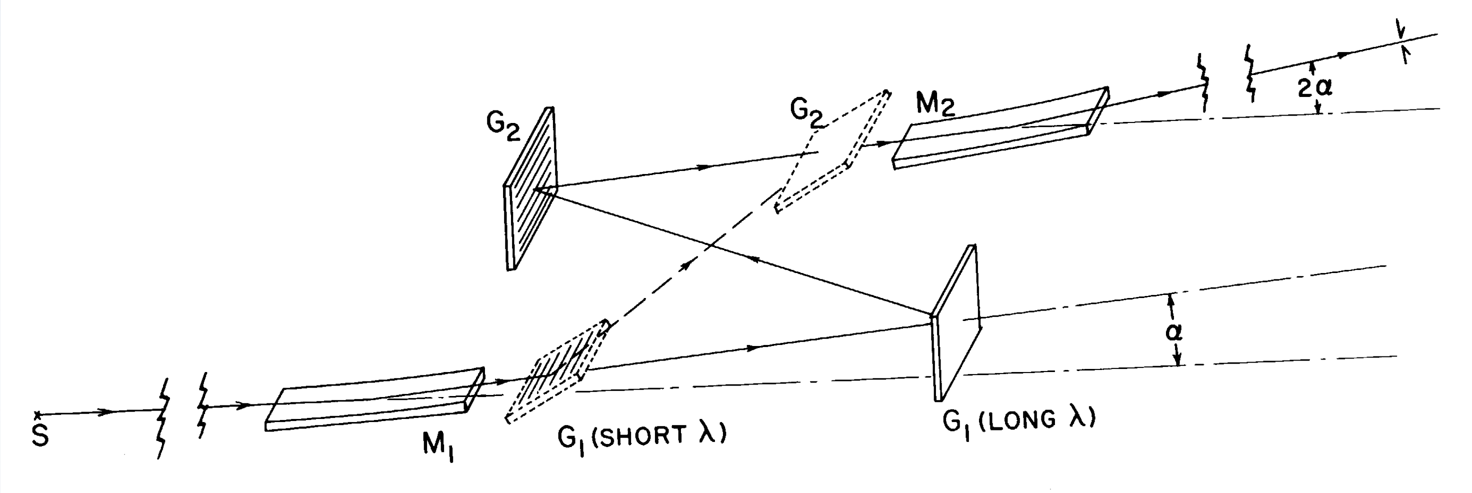
X24C Layout



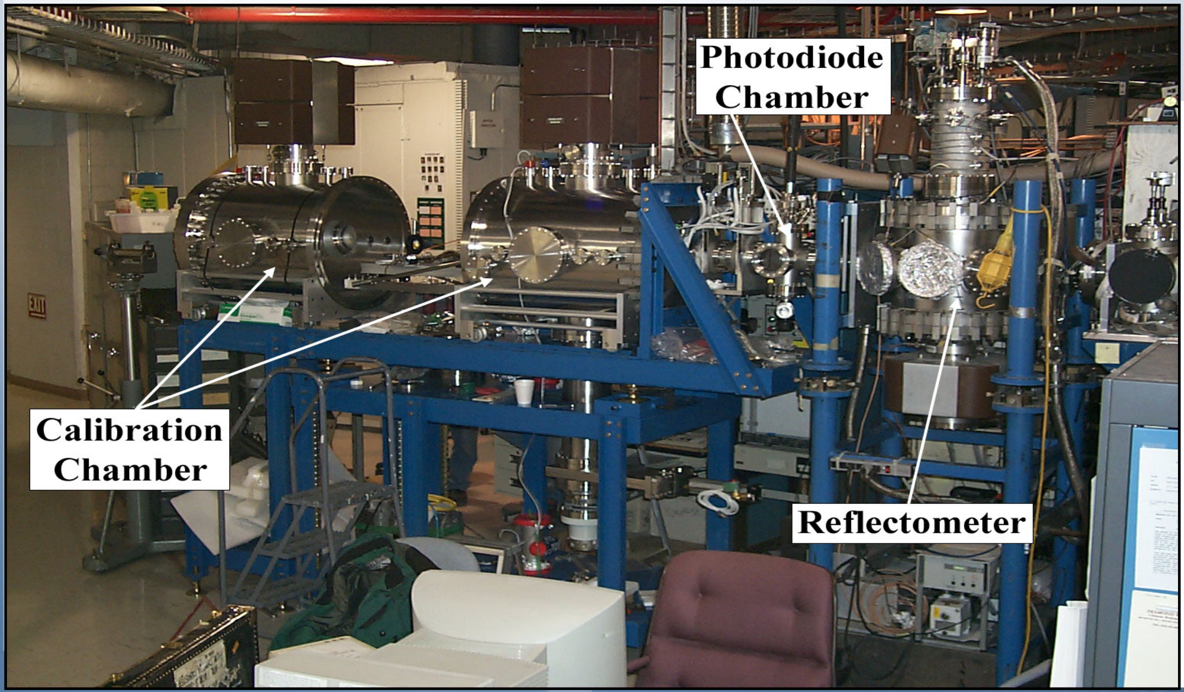
Monochronometer



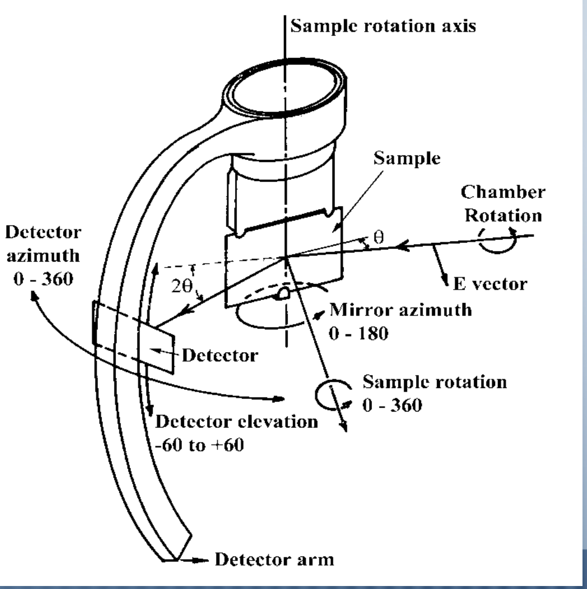
- Monochromator has two elements (e.g. grating and mirror) precisely translated and rotated by computer control while maintaining fixed entrance and exit slits.
- Gratings, selected without breaking vacuum, cover from 1 keV through the visible.
- 10^8 to 10^{12} photons/sec/0.1% bandpass peaking at ~ 100 eV, resolution up to 600.
- Radiation 90% polarized

Sample Chambers

- UHV reflectometer 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.



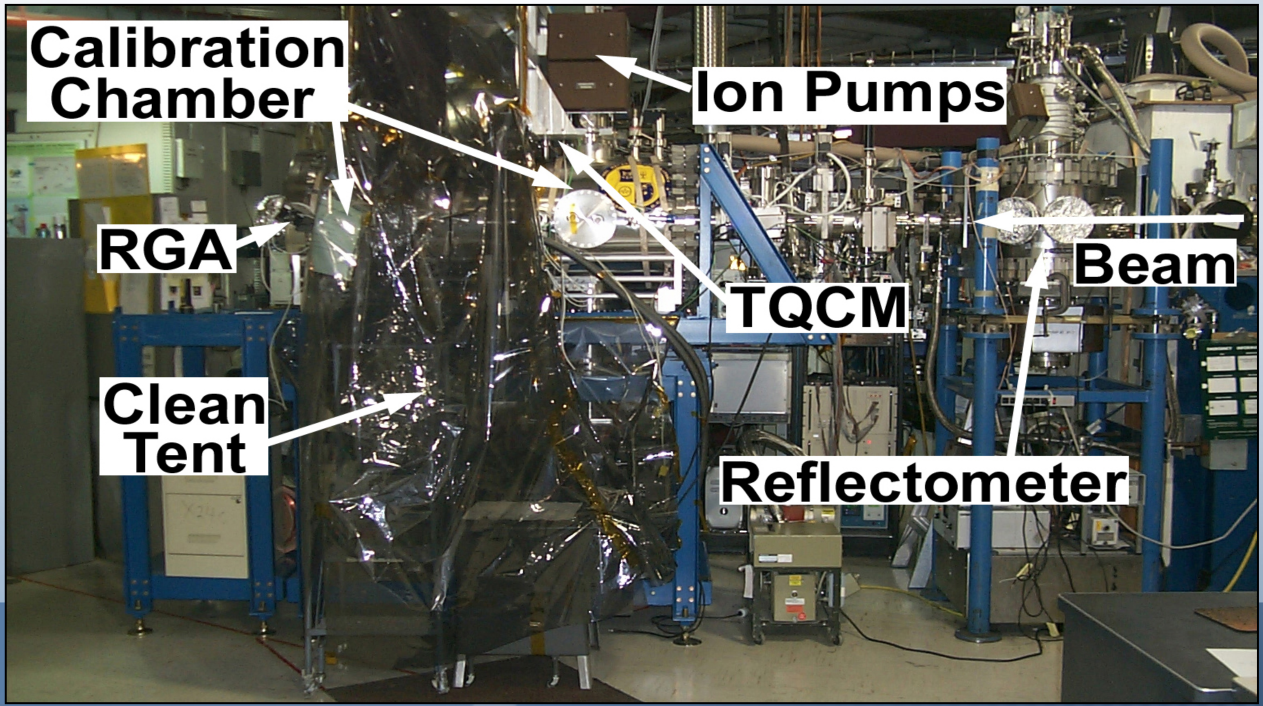
Computer controlled θ-2θ reflectometer:



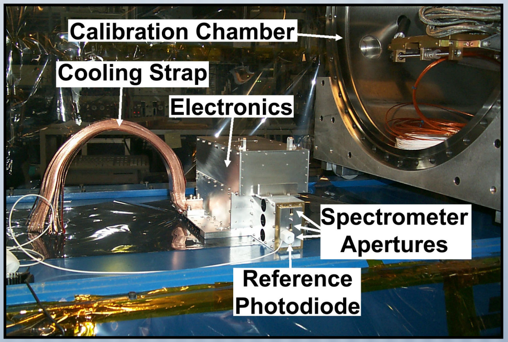
Large Calibration Chamber

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.



GOES N EUVS



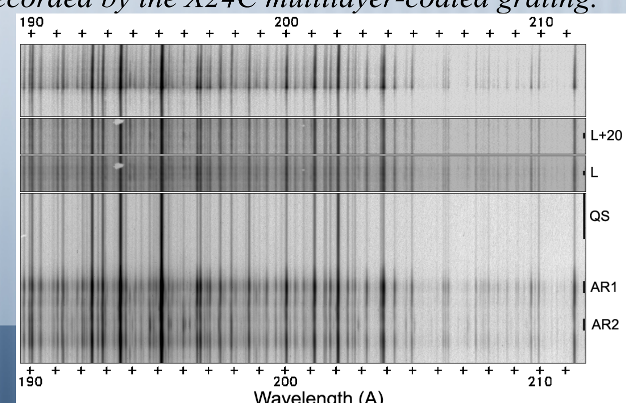
Extreme-Ultraviolet Imaging Spectrometer (EIS) on *Hinode*
First Satellite Multilayer Grating Spectrometer

Motivation: High-resolution solar EUV spectrometers carried on NASA satellites require high grating efficiency at normal incidence. This enables detailed spectroscopic studies of the solar EUV spectrum leading to improved understanding of coronal heating and the generation of the solar wind and coronal mass ejections which affect space weather, the earth's ionosphere, and communication and navigation satellites.

Results:

Reflective Mo/Si multilayer coatings were applied to high-resolution diffraction gratings and were optimized and calibrated at X24C for high grating efficiency in the 17-21 nm and 25-29 nm spectral ranges. A coated grating was incorporated into NASA's EUV Imaging Spectrometer (EIS) built by NRL and an international consortium and launched on the *Hinode* spacecraft in September 2006. The high-efficiency grating enabled the observation of hundreds of new spectral lines for the first time.

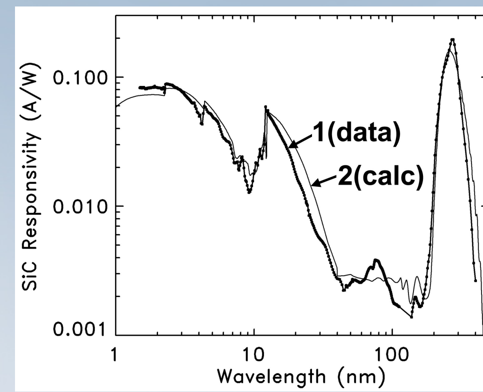
Above: EIS spectrometer on the Hinode satellite. Below: Sample EIS spectral image from solar active (AR) and limb (L and L+20) regions recorded by the X24C multilayer-coated grating.

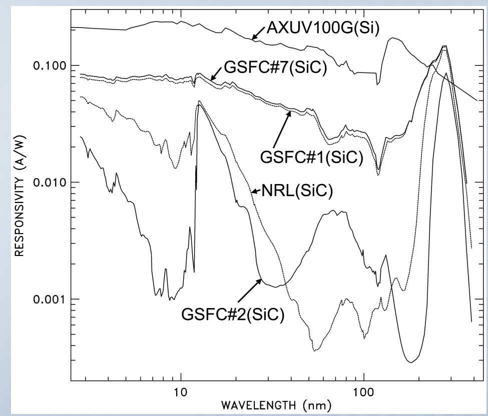


Wide-Bandgap SiC Sensors

J. F. Seely, M. Kowalski, B. Kjornrattanawanich, Naval Research Laboratory (NRL)
Drs. Hu, Xin, Zhao, Yan, and Guan, Goddard Space Flight Center

- The responsivities of several types of SiC sensors were measured in the EUV, FUV, and visible regions.
- These wide-bandgap sensors have low visible light sensitivity (solar blind) and this is very beneficial for accurately measuring the absolute EUV emission from the Sun, where the extremely intense visible radiation can overwhelm the weak EUV signal from solar radiometers.
- It was found that the responsivity was quite sensitive to device fabrication, in particular the surface dead layer material, thickness, and implantation.





The measured responsivities of several SiC sensors and comparison to the calculated responsivity.

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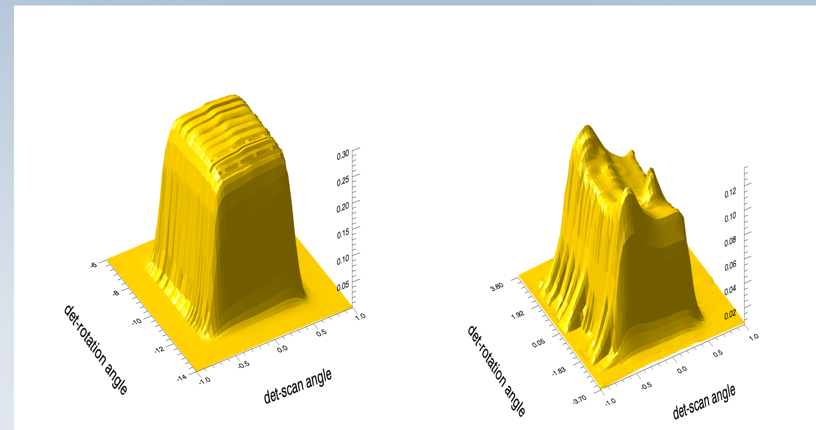
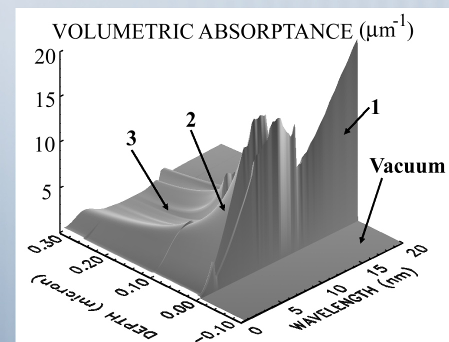
Radiation Damage to Silicon Photodiode EUV Detectors

B. Kjornrattanawanich, John Seely, Naval Research Laboratory (NRL)
Raj Korde, International Radiation Detectors Inc.

- Silicon photodiode Detectors were exposed to long-duration intense EUV monochromatic radiation for the purpose of characterizing the loss of sensitivity due to radiation damage.
- These studies are important for designing spaceflight solar radiometers that can accurately measure the extreme-ultraviolet (EUV) emission from the Sun.
- It was determined that the responsivity decreases in the active region just below the surface dead layer where the volumetric absorptance is highest.
- A computer model that calculates the absorptance, reflectance, and transmittance of an electromagnetic wave at the various interfaces and layers of the device accurately modeled the decrease in the charge collection efficiency.



Above: Responsivities measured at 75 nm wavelength of a pristine silicon photodiode (left) and of an identical photodiode exposed to long-duration 75 nm radiation.
Below: Calculation of the volumetric absorptance as functions of the incident wavelegnth and the depth into the device.



J. F. Seely, B. Kjornrattanawanich, J. C. Bremer, M. Kowalski, Yan Feng, "Radiometry and Metrology of a Phase Zone Plate Measured by Extreme Ultraviolet Synchrotron Radiation," Appl. Opt. ***48****, 5970. (2009).*

Work performed on X24C, the NSLS beamline dedicated to Radiometry and Metrology.

Fresnel Zone Plates for Space Weather Instrumentation

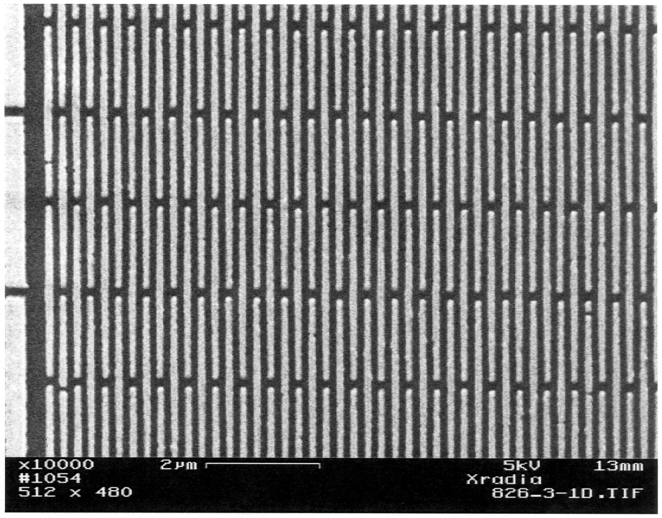
J. F. Seely, M. Kowalski, B. Kjornrattanawanich, Naval Research Laboratory (NRL)
J. C. Bremer, Research Scientific Instruments Inc. and Yan Feng, Xradia Inc.

- Fresnel zone plates have been fabricated and tested for use in spaceflight solar monitors that can accurately measure the extreme-ultraviolet (EUV) emission from the Sun.
- The solar EUV range is the most highly varying component of the solar emission, is absorbed in the earth's upper atmosphere, and controls atmospheric chemistry and variability. The accurate measurement of the solar EUV emission is critically important for understanding solar variability and its effects on the earth's atmosphere and space weather.
- The zone plates are accurately calibrated using synchrotron radiation and are designed to hold their calibration in the hostile space environment, thereby enabling a new generation of solar monitors that can measure the solar EUV irradiance with unprecedented absolute accuracy. The EUV irradiance measurements are essential for the development of computer codes that model atmospheric chemistry and physics, provide predictive capabilities for protecting civilian and military space and terrestrial assets, and provide long-term modeling of solar variability and climate change.

SEM Micrograph

Scanning electron microscope image of the zone plate.

Outermost zones



Scanning Electron Microscope (SEM) image of the outermost zones (dark vertical lines), open spaces between the zones (white regions), and cross linking of the zones for support. The zones are opaque to EUV radiation and diffract the radiation onto the axis of the zone plate with focal length that varies inversely with the radiation wavelength.

Supported by NASA project NNH09AK121, "Ultra-Stable Extreme Ultraviolet Solar Monitor using Zone Plates"

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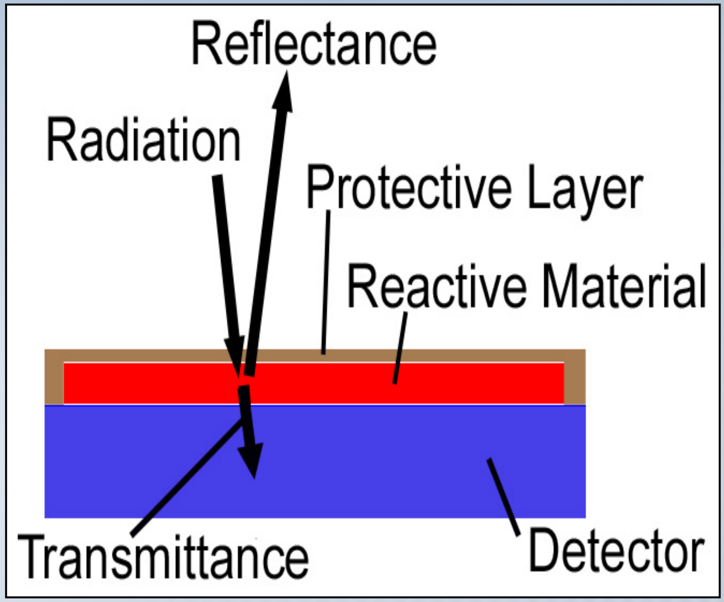
Optical Properties of Rare Earth Elements for Solar Spectroscopy

B. Kjornrattanawanich and J. F. Seely, Naval Research Laboratory (NRL)
D. Windt, Reflective X-Ray Optics LLC

- The measurement of the optical properties of the rare earth elements has enabled a new class of highly reflective multilayer coatings in the extreme-ultraviolet (EUV) wavelength region. These coatings will be applied to mirrors and diffraction gratings that are used in NASA and DOD spaceflight instruments for accurately measuring the solar EUV spectrum.
- The rare earth elements have weakly bound outer electrons that provide transmission windows at EUV wavelengths for solar imaging and spectroscopy, but they are also highly reactive and readily oxidize. A novel technique using protective buffer layers of stable materials was developed by NRL scientists for accurately measuring the optical properties of thin, pure rare earth layers.
- Highly reflective multilayer coatings using thin layers of rare earth elements were fabricated and have excellent long-term stability thus enabling a new generation of high-resolution solar telescopes and spectrometers in the EUV wavelength region.



A novel technique for measuring the optical properties of the rare earth elements was developed by NRL scientists. The reactive material layer (of a rare earth element, shown in red) is applied to a photodiode detector substrate (blue) and is immediately covered by a thin layer of a stable material that prevents oxidation of the underlying reactive layer. The transmittance and reflectance of the layers are measured and are used to derive the complex index of refraction of the rare earth material

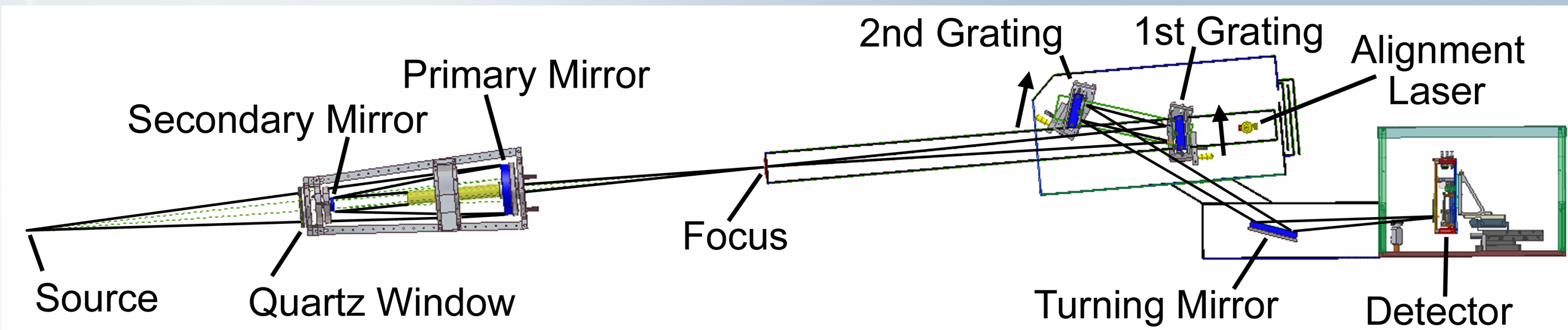
B. Kjornrattanawanich, D. L. Windt, J. F. Seely, "Normal-Incidence Silicon-Gadolinium Multilayers for Imaging at 63 nm Wavelength," Optics Letters 33, 965 (2008)

Work performed on X24C, the NSLS beamline dedicated to Radiometry and Metrology.

U.S. Department of Energy | Office of Science   Brookhaven National Laboratory

Radiometry Calibrations Enable Laser-Fusion Research

C. M. Brown, J. F. Seely, and Uri Feldman, Naval Research Laboratory (NRL)



- Progress in DOE and DOD research directed toward the production of energy by the laser-fusion process depends on the accurate understanding of the laser energy absorption by the target plasma and the generation of laser-plasma instabilities (LPI) that can disrupt the laser-plasma coupling.
- NRL scientists have developed and calibrated a high-resolution imaging spectrometer that is used to accurately measure the most detrimental LPI process, the two-plasmon decay instability that results in plasma radiation emission at 2/3 the laser wavelength.
- The spectrometer is used to optimize the laser properties to promote efficient laser-plasma coupling such as laser wavelength, pulse duration, intensity, and beam smoothing.

The imaging spectrometer consists of a two-mirror Cassegrain telescope and a two-grating spectrometer that images the plasma radiation onto a detector. The recorded spectral image is of the plasma emission at 2/3 the laser wavelength that is generated by the two-plasmon decay instability that can disrupt the laser-plasma coupling.

C. M. Brown, J. F. Seely, U. Feldman, G. E. Holland, J. L. Weaver, S. P. Obenschain, B. Kjornrattanawanich, and D. Fielding, "High-Resolution Imaging Spectrometer for Recording Absolutely Calibrated Far Ultraviolet Spectra from Laser-Produced Plasmas," Rev. Sci. Instr. ***79****, 103109 (2008).*

Work performed on X24C, the NSLS beamline dedicated to Radiometry and Metrology.