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NIST VUV metrology programs to support space-based research

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Abstract

Vacuum ultraviolet (VUV) radiation, spanning the electromagnetic spectrum from about 2 nm (620 eV) to 200 nm (6.2 eV) has long been important in astronomy, solar physics, and Earth observing systems, among other applications. The National Institute of Standards and Technology (NIST) has several programs to serve the VUV user community, from the Synchrotron Ultraviolet Radiation Facility (SURF III) – a standard of irradiance from 2 to 400 nm – to measurement and calibration services for mirrors, photodiodes, and filters. We have recently reduced the uncertainty of our extreme ultraviolet (EUV) detector calibrations by implementing an absolute cryogenic radiometer on one of the SURF beamlines, and have effected several improvements to the EUV detector calibration beamline at SURF. We continue to investigate wide-bandgap semiconductors for use as solar-blind detector technologies, and have recently obtained quantum efficiency and uniformity data from 1 cm^2 active area GaN and SiC photodiodes.

Keywords: Radiometry; Vacuum ultraviolet; VUV; Extreme ultraviolet; EUV; Photodiode; Reflectometry; Wide-bandgap; Space instrumentation; Calibration

1. Introduction

The National Institute of Standards and Technology (NIST) has a wide variety of programs for the calibration of instruments and components for space-based research in the vacuum ultraviolet. Many of these programs have been in existence since the 1960s, and have provided calibration support to NASA and international missions since that time.

Radiometric calibration of detectors, sensor packages, and entire spacecraft instruments is available in the vacuum ultraviolet (VUV) spectral range from 2 to 254 nm. NIST issues transfer standard detectors, either solar-blind photoemissive detectors or solid-state Si photodiodes, in this spectral range with relative expanded uncertainties from 2% to 20%. (All uncertainties in this paper are stated as expanded uncertainty with coverage factor $k = 2$, i.e., 2σ uncertainties.) End-to-end calibration of entire instruments is available at several synchrotron beamlines using either detector-based or source-based standards. NIST is collaborating with several developers of novel detector technologies, especially in the characterization of new wide-bandgap semiconductors that can be used as solar-blind, solid-state photodiodes.

In addition to radiometric calibrations, NIST has facilities for the measurement of reflectivity as a function of position, angle of incidence, and wavelength. Many multilayer mirrors for extreme ultraviolet (EUV) space-based telescopes have been calibrated here. Facil-

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ities are available for the measurement of the transmission of thin-film and crystalline windows throughout the VUV spectral region. The zero-order and diffraction efficiency of EUV transmission gratings can be measured as well.

2. Sources and calibration facilities

NIST operates a number of facilities for the EUV radiometry program. These include a low-pressure plasma discharge and a normal-incidence monochromator, a laser-produced plasma for pulsed measurements, and a synchrotron radiation facility with several beamlines dedicated to radiometry.

2.1. FUV Detector Calibration Facility

In the Far Ultraviolet (FUV) Detector Calibration Facility a low-pressure plasma discharge source is operated to produce radiation with wavelengths longer than 50 nm. While the source also produces shorter wavelength radiation, a normal-incidence monochromator is used for the measurements here. The source, called a "duoplasmatron," was originally developed as an ion source, but was adopted as a source of neutral and singly ionized atomic and molecular emission (Samson, 2000). The plasma is generated by electrons emitted from a hot filament and accelerated through a gas by an applied electric field. Permanent magnets surround the plasma chamber and generate an axial magnetic field that pinches the plasma and increases the source's brightness.

This facility has a 1 m focal-length, normal-incidence, spherical-grating monochromator to provide radiation to the experimental chamber. The duoplasmatron is operated with one of several gases (He, Kr, Ar, Ne, or H_2) to produce the desired spectrum. All of these source gases produce atomic (primarily neutral and singly ionized) emission lines. The H_2 plasma also emits many molecular lines and a molecular continuum at wavelengths longer than 170 nm.

Instrumentation exists for a variety of experiments in this facility. The most common measurement is detector quantum efficiency, however the capability to measure the transmission of thin-film filters and crystalline windows and the spatial uniformity of a photodiode's responsivity is also available. The detector calibration can be repeated during an extended exposure to determine the detector's radiation hardness. The typical wavelength range of this facility is 50–254 nm. Although longer wavelengths are available from the source and monochromator, another laboratory at NIST is better suited to perform calibrations in the near ultraviolet and visible spectral ranges (NIST, 2004).

All three of the transfer standard detector types described in Section 3 are calibrated in this facility. The absolute detector that is the head of the calibration chain is either a double-plate ionization chamber (described in Section 4.2) from 50 to 92 nm or an absolute cryogenic radiometer (described in Section 4.3) from 130 to 254 nm. The ionization chamber is operated in this facility, but the radiometer is operated on Beamline-4 (BL-4) at the Synchrotron Ultraviolet Radiation Facility (SURF III) described in Section 2.3.3.

2.2. Pulsed radiometry for EUV lithography

In the EUV Lithography (EUVL) Pulsed Radiometry Facility we operate an EUV laser-produced plasma source (Parra et al., 2002) that is similar to sources being considered for use in commercial lithography systems. The NIST source injects gas clusters or droplets into a vacuum chamber by means of a pulsed valve. A Q-switched laser is focused onto the gas and generates a plasma with high ionization states. The plasma emits in a broad spectrum, but proper selection of the target gas can optimize the source for 13.5 nm, the EUVL operational wavelength. This source can operate with either Kr or Xe as the target gas and uses a 10 W average power Nd:YAG laser at either the 1064 nm fundamental emission or the 532 nm frequency-doubled wavelength. The EUV emission from the plasma is pulsed, with a pulse length of approximately 10 ns. The typical operating frequency is 1 Hz.

This facility is instrumented for the calibration of EUVL source diagnostics tools and EUV detectors in the pulsed illumination conditions found in EUVL wafer exposure systems. Typically, the source is imaged onto both a normalization detector and a second detector, either the detector under test or the in-house working standard detector. The signal from the normalization detector allows us to account for the shot-to-shot variation in the source radiance. The calibration is performed by interchanging the detector under test and the working standard in the vacuum chamber.

All the working standard detectors in this facility are calibrated at the EUV Detector Radiometry Beamline (BL-9) at SURF III (see Section 2.3.4). The calibration is established in a low-power, continuous beam of radiation. We are currently studying (Vest and Grantham, 2003) the response of solid-state photodiodes to short, high-peak-power pulses of radiation to understand how best to transfer low-power, cw calibrations to pulse energies typical of EUVL applications.

2.3. Synchrotron Ultraviolet Radiation Facility (SURF III)

The Synchrotron Ultraviolet Radiation Facility (SURF III) is one of the oldest sources of synchrotron