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XUV Polarimeter for undulator radiation measurements

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ABSTRACT

A polarimeter for x-ray and vacuum ultraviolet (XUV) radiation was built to measure the spatial and spectral dependence of the polarization of the light produced by the new undulator at the U5 beamline at NSLS. The fourth-harmonic radiation was measured, and it does not agree with predictions based on ideal simulation codes in the far-field approximation.

INTRODUCTION

The availability of synchrotron radiation has had a dramatic impact on a diverse array of multidisciplinary spectroscopies. In recent years the variability of the polarization of synchrotron radiation has been utilized in widespread applications,^{1,2,3} including spin-polarized photoemission, inverse photoemission, circular dichroism, *etc.* The gathering and interpretation of such measurements are greatly simplified by taking advantage of the polarization properties of synchrotron sources. This is

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especially the case for the latest generation of undulator- and wiggler-based experiments. However, the approach suffers from the fact that the actual spatial and spectral distribution of polarization states of a given source has rarely been measured. Rather, the procedure has been that each experimentalist is forced to rely on the polarization properties calculated for an "ideal" source. But, the calculations are limited in their accuracy largely because of both the finite beam emittance of the source, and the presence of random errors in the magnetic profiles of the insertion device. These factors can significantly alter the polarization. Therefore, as the need for polarized-light sources increases, there is a concomitant need for accurate measurements of the polarization over a wide spectral range.

Recently considerable developmental work^{7,8,9} has been devoted to polarization measurements for soft x-ray and vacuum ultraviolet (VUV) synchrotron radiation. The first soft x-ray polarimeter was developed by Gluskin, *et al.* to measure the radiation from a helical undulator.¹⁰ The aim of the present work is the development of an advanced polarimeter to characterize the polarization of the radiation from the new undulator recently installed at the U5 beamline on the VUV-ring at the National Synchrotron Light Source (NSLS) at Brookhaven National Laboratory. The radiation from the U5 undulator is used for spin-polarized photoemission experiments. In these experiments undulator radiation is needed to partially compensate for the known inefficiencies of the electron spin detectors.

EXPERIMENTAL BACKGROUND

The U5 undulator is a planar insertion device with the following parameters:¹¹

Undulator Period	$\lambda_0 = 7.5 \text{ cm}$
Number of Period	$n = 27$
Deflection parameter	$K = 2.3$
Distance	
Undulator to Pinhole	5.4 m

The K-value is actually variable, but for the present work it was fixed at the above value. The undulator is a hybrid design based on Nd-Fe-B permanent magnets and vanadium permendur pole pieces.

The polarization measurements were performed by the polarimeter schematically shown on Fig. 4. The polarimeter consists of five sets of Mo/Si multilayer polarizers placed in the ultrahigh vacuum (UHV) chamber and supported by a 5-axis goniometer assembly. These polarizers take advantage of the property that metals have an index of refraction $n \approx 1$ for photon energies above ~ 58 eV, and, thus, have a Brewster's angle of 45° . Additionally, by designing the polarizers as multilayer structures one can selectively enhance a particular wavelength with the proper choice of the multilayer period. Then, by placing a polarizer at 45° with respect to the incident beam one simply has to measure the intensity of the reflected light to measure the *s*-polarized component of the incident light (scaled by the reflectivity of the multilayer). By rotating this assembly over 180° one can measure all the linear polarized components of the incident light. Note that there is one limitation to this method which is that circular and non-polarized light cannot be distinguished without separate measurements utilizing the equivalent of a quarter-wave plate.

Five different Mo/Si multilayer Bragg-reflectors were used as polarizers for the energy region 58-98 eV. Each was designed to have its maximum reflectivity at an angle of incidence of 45° for a different specific energy range that encompassed that of the first five harmonics of the undulator. Further, the polarimeter design permits the positioning of any of the five multilayers onto the analyzed beam without breaking vacuum.

Mechanical adjustments provide the ability to align the polarizer axis of rotation parallel to the incident beam axis to within 0.1-mrad accuracy. These adjustments also allow us to translate the polarimeter with respect to the beam center with a $10\text{-}\mu$ accuracy. The rotation of

the polarizer/detector assembly is controlled to within a 0.1° accuracy. An illuminated area of 25×25 mm can be analyzed with the spatial resolution of 0.01 mm by means of one of three different pinholes on the polarimeter. A GaAs Schottky diode with an active area of 5×5 mm or a UDT Si diode with a 10×10 -mm active area were used as detectors because of their spatial uniformity and sensitivity.

RESULTS

Energy spectra will be presented first and then the polarization information will be presented. A typical energy spectrum from the U5 undulator is shown on Fig. 1. The spectrum was measured with a 1-mm diameter pinhole placed on the center of the irradiated area (see Fig. 2). The spectrum was collected by measuring the photocurrent from a Ni target, and was not normalized to take into account the quantum efficiency of Ni. The ratio of intensities between the wide and narrow parts of the fifth harmonic located between 90-100 eV is not reproduced in the computer simulations but the transmission function of the monochromator may be the source of this discrepancy.

Next the energy dependence of the radiation was measured for various horizontal displacements of the pinhole in the plane of the storage ring. Three of these spectra are shown in Fig. 3. From these spectra we see a strong left-right asymmetry in the radiation emitted from the U5 undulator. This asymmetry is not present in calculated spectra using present-day algorithms. These types of measurements confirm the need for comprehensive experimental characterizations of undulator sources.

For the polarization measurements five multilayers were chosen to span the energy region of the undulator harmonics. Spectral reflectivity measurements of the polarizers were performed at the SURF II beamline at NIST.¹³ The results for two of the polarizers are shown superimposed with measurements of the undulator spectra in Fig. 5. The polarization measurements were conducted by first rotating the analyzer/detector assembly of the polarimeter to the position shown schematically in Fig. 4b. This position is designated as -90° . In this configuration the detected beam

is completely polarized perpendicular to the plane of the storage ring. Then the intensity measured by the detector is recorded as the assembly is rotated by 180° to the $+90^\circ$ position. A typical scan is shown in Fig. 6. The data show the expected fit to a $\cos^2(\theta)$ angular dependence (the solid line). A series of such scans were performed for different vertical positions by translating the polarimeter above or below the plane of the storage ring. Two of these scans are shown in Fig. 7. The data were taken using the multilayer which selected out the fourth-harmonic radiation at ~ 75 eV. The unusual feature to focus on is that the off-axis data in Fig. 7 appears to be superimposed on a background signal; this produces the wings at high angles compared to the on-axis data. The shape of the curve indicates that the off-axis light either becomes elliptical or includes an unpolarized component. While we cannot distinguish between the two possibilities, neither are predicted by the ideal simulation codes.

CONCLUSION

In summary we have built and tested a XUV polarimeter capable of measuring the polarization from VUV and soft X-ray synchrotron sources, including insertion devices. Our first measurements of the polarization of the U5 undulator at NSLS indicate that there are significant contributions to the light that cannot be explained with calculations that use the "far-field" approximation. This has significant implications for the characterization and utilization of the new types of insertion devices, such as helical or crossed undulators, and asymmetric wigglers, that are being developed exclusively for the production of variable polarization radiation.

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Figure 1. Typical spectrum from U5 undulator. Measurements were taken with 1-mm pinhole at the center of the photon beam, and collected by measuring the photocurrent from a Ni target.

Figure 2. Schematic layout of the U5 beamline.

Figure 3. U5 undulator spectra taken with a 1-mm pinhole nominally at the vertical center of the beam for three different horizontal positions: 3 mm to the right (top), at the beam center (center), and 3 mm to the left (bottom)

Figure 4. Schematic depicting the operation of the polarimeter for the measurement of horizontally (top) and vertically (bottom) polarized components of the undulator beam. The labels refer to: 1, undulator; 2, pinhole used upstream of the polarimeter; 3 multilayer Bragg-reflectors mounted at 45° with respect to the incident beam; 4 photodiode detector. (Note that items 3 and 4 always rotate together, thus they always remain in the same position relative to each other.)

Figure 5. Left scale shows an on-axis spectrum of the U5 undulator. The right scale shows the measured reflectivity of two of the multilayer Bragg-reflectors used for the polarization measurements. Note that each multilayer selects a different harmonic (the third and fourth).

Figure 6. Typical data (open circles) from polarization measurements as the polarizer/detector assembly rotates from -90° to 90° . The solid line is the best fit to a $\cos^2(\theta)$ angular dependence of the measured intensity.

Figure 7. Measured polarization as a function of angle for polarimeter located on the photon-beam center (boxes), and for the polarimeter located 2 mm below the beam center. Note that the lines serve only as a guide to the eye.