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Characterization of a Novel Elliptically Polarized Wiggler

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We report on the initial characterization of an elliptically polarized wiggler built by a collaboration between the Advanced Photon Source, the Institute of Nuclear Physics, and the National Synchrotron Light Source. The wiggler has recently been installed in the X13 straight section of the NSLS X-Ray ring. The device consists of a vertical permanent-magnet wiggler and a horizontal electromagnet wiggler. The electromagnets allow the wiggler to produce on-axis circularly polarized soft x-rays with the capability of AC modulation of the polarization. The maximum switching frequency that can be reached is 100 Hz.

The degree of circular polarization of the radiation from the wiggler was characterized by making magnetic circular dichroism measurements using the X13A soft x-ray beamline. For a vertical deflection parameter, K_x , of 1.6, the dichroism effects at the Fe $L_{2,3}$ edges indicate a degree of circular polarization of approximately 75% using an aperture with a vertical acceptance of 87 μ rad. Because both the left- and right-circularly polarized photons traverse identical paths through the beamline optical system, significantly smaller intensity fluctuations associated with switching of the polarization were observed than are typically possible at bending magnet beamlines. This, together with the relatively fast modulation rate, means that it will now be feasible to perform a variety of experiments that have not been possible using bending magnet sources.

1. INTRODUCTION

Circularly polarized VUV and soft x-ray beams have been used for many years as experimental probes in a wide variety of scientific disciplines covering the biological, chemical and physical sciences. More recently, there has been increasing demand for circularly polarized soft x-ray beams, particularly in the energy region from 500 eV to 2000 eV covering the important $L_{2,3}$ and $M_{4,5}$ transitions of the transition metals and rare earth magnetic materials, respectively. Because optical

schemes for manipulation of the beam polarization have not been demonstrated over this energy region, one has little choice but to use a source of variable polarization. The first experimental demonstration of soft x-ray magnetic circular dichroism was performed by Chen *et al.*¹ In their experiment, bending magnet radiation alternately selected from either above or below the storage ring orbit plane resulted in an elliptically polarized x-ray beam at the sample with alternately opposite polarization. Since that time, several soft x-ray beamlines have been built or modified to utilize the off-axis elliptical polarization

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component from a bending magnet. Insertion devices with *controllable* polarization² would appear to offer significant advantages in this field. We present characterization measurements from such a device.

2. THE ELLIPTICAL MULTIPOLE WIGGLER

The elliptical multipole wiggler (EMW) has been built as a collaborative effort between the Advanced Photon Source, the Budker Institute of Nuclear Physics, and the National Synchrotron Light Source (NSLS).³ The device, which is installed at the X13 straight section of the NSLS X-Ray ring has 7 vertical permanent magnet poles, 10 horizontal electromagnet poles, and a period of 16 cm. The vertical gap and horizontal electromagnetic field can be varied to tune the vertical and horizontal deflection parameters, respectively. The magnetic fields measured in this device with typical deflection parameters of $K_x=1.6$ and $K_y = 12$ are shown in figure 1.⁴

One specific advantage of using horizontal electromagnets is that the horizontal magnetic field can be rapidly reversed, thereby reversing the polarization of the on-axis elliptically polarized x-rays. The present device has been designed and successfully tested with switching frequencies up to 100 Hz. Such high frequency operation is clearly impossible with devices relying on mechanical translation of permanent magnet assemblies.

Another attractive feature of the EMW compared with a bending magnet source and some other types of insertion devices is that the elliptically polarized radiation is generated in the orbital plane. In the EMW, an aperture is necessary to remove the two out-of-plane linearly polarized components having vertical deflection angles of K_x/γ . Reversal of the on-axis x-ray beam ellipticity is achieved by reversing the EMW horizontal field direction. This means that an identical optical path is traversed for both polarization components. In out-of-plane configurations this is typically not the case, which can result in intensity differences of several percent between the two components.

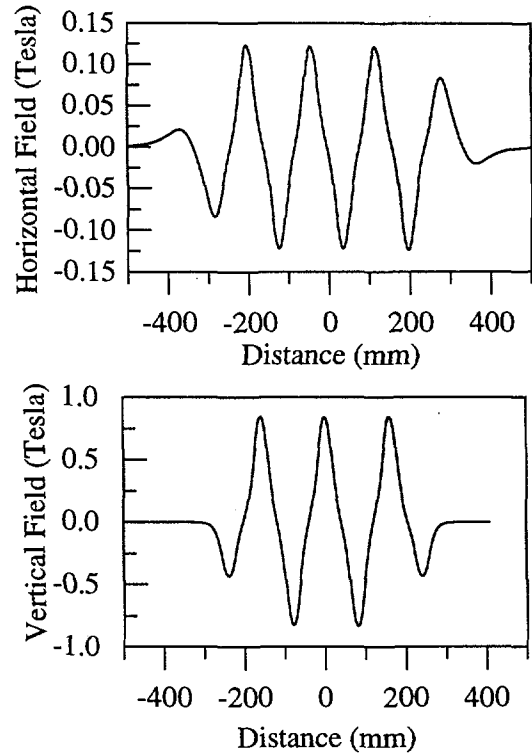


Figure 1. EMW horizontal and vertical magnetic fields⁴

3. MEASUREMENTS

The measurements presented here were taken with the EMW and the X13A soft x-ray beamline.⁵ A spherical grating monochromator covering the energy range from 300 to 1200 eV was used to monochromatize the wiggler radiation. The grazing incidence optics of this beamline ensure that the source polarization is fully preserved at the sample. The vertical gap of the EMW was set to give a deflection parameter K_y of 11.5. The electromagnet current was adjusted to 400 A, corresponding to a K_x of 1.1, with a switching frequency of 2 Hz. The monochromatized beam was passed through an aperture in front of the sample. The aperture was mounted on a linear actuator for alignment with the center of the beam. The aperture could also be scanned for beam profile measurements. The aperture, located 23 m from the source, is 2 mm

high, corresponding to a vertical acceptance of 87 μ rad. The horizontal acceptance of the beamline was limited to approximately 0.5 mrad by a horizontally deflecting mirror.

The circular polarization of the monochromatized beam was measured by taking magnetic circular-dichroism measurements of thin magnetic films. The films were deposited on GaAs wafers mounted on a manipulator in a UHV sample chamber. A permanent magnet generated a field of up to ~ 0.5 Tesla at the sample surface. The photoemission current from the sample was measured as a function of photon energy. The signal from the sample was synchronized with the switching of the EMW field, digitized, and fed into separate "left-polarization" and "right-polarization" counters.

As an example from our measurements, the MCD signal taken at the Fe $L_{2,3}$ edge is shown in figure 2. This spectrum is shown without normalization to the beam intensity or correction of the beam incidence angle of 45° . The characteristic MCD spectrum indicates a maximum dichroic signal of approximately 14% at the L_3 edge, at *ca.* 708 eV.

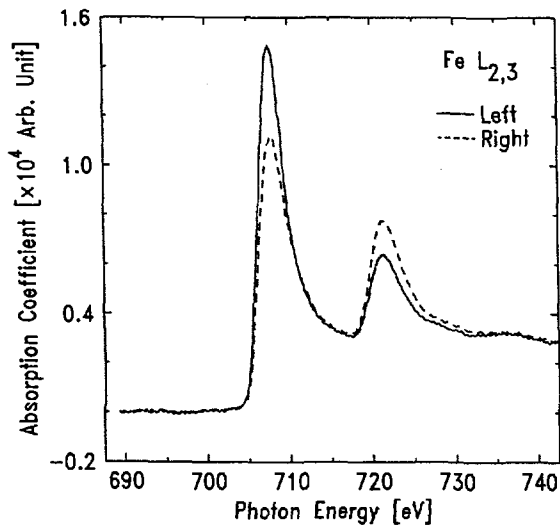


Figure 2. MCD measurement at the Fe $L_{2,3}$ edge

The difference in intensity of the left and right channels (as measured on a separate I_0 mesh in front

of the sample) was measured to be less than 1% in all cases. However, we noted that the difference was not constant but had an apparent linear energy dependence. We also observed small periodic oscillations of the I_0 , which can be seen at approximately 694, 700, and 738 eV in figure 2. By normalizing to the I_0 signal, the data can be corrected to remove both the linear and oscillating background from figure 2.

In addition to the I_0 measurements, we also noted an unexpected intensity distribution from the EMW when viewing the beam on a fluorescent screen upstream of the monochromator. With no vertical aperture present, one observes two bright horizontal lines, one above and the other below the orbit plane, separated by a vertical deflection angle of K_x/γ as expected. In addition, we observed that one of the lines was brighter than the other and that the pattern oscillated in synchronization with the electromagnetic field.

4. DISCUSSION

Comparison of the MCD measurements reported here with data⁶ taken at NSLS Dragon Beamline, U4B, indicates that the wiggler radiation has a circular polarization rate, S_3 , of between 60 and 65% at the Fe L_3 edge with $K_x = 1.1$. Results taken at $K_x = 1.6$ show that S_3 increases to approximately 75%. This agrees well with the calculated results shown in figure 3.

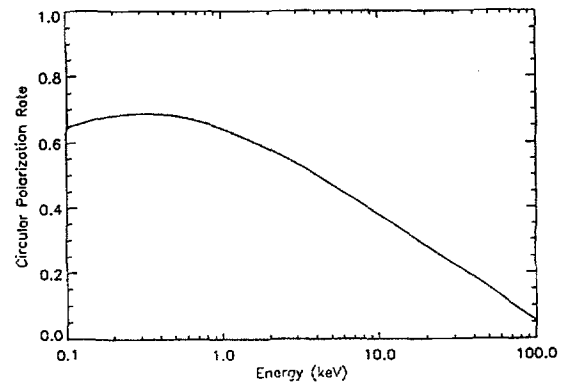


Figure 3. Calculated circular polarization of the EMW

Our current understanding of the asymmetric vertical intensity distribution is that it is the result of the symmetric (w.r.t. reflection in vertical axis through the center of the device) vertical magnetic field (figure 1). This configuration was chosen because it is then easier to compensate the asymmetric, time-dependent horizontal field. Although the magnetic lattice was carefully adjusted to have a negligible vertical field integral, the radiation characteristics of the two half-strength end poles will differ from those of the full poles. This can be qualitatively explained by approximating each of the vertical poles by bend magnet sources. In this approximation, the end poles have a critical energy of half that of the full poles. Because the vertical angular distribution of radiation from a bending magnet is a function of the photon energy and also depends on the critical energy, we expect the asymmetry of the vertical field to be evident as an energy-dependent asymmetry in the vertical angular distribution.

The oscillations in the background signal are thought to be due to undulator-like interference effects in the radiated field, as qualitatively seen in calculations. Future study periods will be dedicated to investigating this effect.

5. CONCLUSION

The EMW behaves largely as predicted. The in-plane production of elliptically polarized radiation results in intensity differences of less than 1%. This will now make it possible to perform measurements on extremely dilute or weakly coupled systems that would otherwise be extremely difficult in out-of-plane configurations. By changing the symmetry of the vertical magnetic field, we believe that the small intensity differences will be reduced further. We hope that our characterization of the EMW will be extremely useful to designers of future insertion devices of controllable polarization.

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