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The Spin- and Angle-Resolved Photoelectron Spectrometer

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ABSTRACT

A spin- and angle-resolved x-ray photoelectron spectrometer for the study of magnetic materials will be discussed. It consists of a turntable with electron lenses connected to a large hemispherical analyzer. A mini-Mott spin detector is fitted to the output of the hemispherical analyzer. This system, when coupled to a synchrotron radiation source will allow determination of a complete set of quantum numbers of a photoelectron. This instrument will be used to study ferromagnetic, antiferromagnetic and nonmagnetic materials. Some prototypical materials systems to be studied with this instrument system will be proposed.

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Key Words: Spin polarized photoemission, x-ray magnetic dichroism, electronic structure.

Recent studies have demonstrated that excitation of the photoelectrons via circularly polarized photons results in additional sensitivity to the element and site specific local magnetic order via the dipole selection rules[1-6]. The utility of spin resolved experiments have been demonstrated both experimentally[7- 10] and theoretically[11-13]. However, combining high angular resolution x-ray photoemission with spin resolving capability poses significant experimental challenges.

A new compact angle resolving spin spectrometer for conducting such double polarization experiments was developed for this purpose. This spectrometer combines a large (11 inch) diameter fixed hemispherical analyzer with a novel rotatable input lens system allowing data with ±1 degree angular resolution to be acquired for any combination of incident and emission angles as shown in Figure 1. The analyzer is equipped with both multichannel detection for high resolution (50meV) spin integrated spectroscopies and a Mini-Mott detector capable of resolving the photoelectron spin polarization along the two perpendicular axes of the horizontal plane which contains the sample normal and the incident ray of the photon beam. Switching between spin integrated and spin resolved modes is achieved by focusing the photoelectrons through a small hole in the detector of the hemispherical analyzer and into a compact Mini-Mott detect behind the channel plates.

The combination of fixed hemispherical analyzer and rotating lens assembly has advantages over other spectrometer designs. The input lens assembly can collect photoelectrons from any emission angle while the two measurement axes of the Mini-Mott detector remain fixed. This considerably simplifies the interpretation of spin polarization data. The positioning of the analyzer beneath the chamber results in a spectrometer footprint that is smaller than most conventional XPS systems. In addition, the small, in-situ lens assembly causes minimal obstruction of the area around the sample without compromising the resolution and throughput; as would be the case with a conventional small, rotating hemispherical analyzer. The addition of a small hole through the first bending element also allows for normal incidence / normal emission experiments to be conducted; a high symmetry geometry that is important for verification of theoretical models.

The high energy resolution with high throughput is achieved with an 11-inch diameter hemispherical analyzer supplied by Physical Electronics. The novel aspect of the analyzer is that the multichannel detector on the exit of the analyzer has a hole in the center, permitting the direct passage of energy analyzed electrons into the electron optics of the Mini-Mott detector. The presence of the hole does cause an increase in dark counts for non-spin detection but this simply adds a constant background to each spectrum.

Spin resolution is achieved by directing the electrons through the optics and into the Mini-Mott detector. Since the spin resolved detection does not require precise imaging, the burden of high resolution spatial imaging is lifted from the 90°sectors. This allows the 90°sectors to be operated at high pass energies, optimizing throughput. In the Mini-Mott, the electrons are accelerated to 24 kV, with four channeltrons positioned with two measuring the spin component longitudinally along the incident photon beam direction and two measuring the spin component transverse to the photon beam in the plane of incidence of the photon beam. The spin component perpendicular to the plane of incidence is not measured. Despite a relatively low figure of merit, the Mini-Mott has two advantages in our design. First, it provides essentially turn-key operation with the requirement of no special preparation. Second, it has been shown that the electron optical matching of a spin detector to a large hemisphere can be optimized by the use of a Mini-Mott.

Figure 2 illustrates a variety of experiments that can be performed with the system. In part A, the "double polarization" experiment with circularly-polarized incident photons and spin detection, the Mini-Mott detector exhibits a left-right (L-R) asymmetry which inverts upon changing the helicity of the radiation from left-circularly polarized (LCP) to right-circularly polarized (RCP). Part B shows the case for a ferromagnetic sample with perpendicular magnetization with normally-incident linearly polarized (LP) radiation (s-polarized[14]). Changing the magnetization from –M to +M again inverts the left-right asymmetry of the Mini-Mott. In part C, the in-plane magnetized sample with s-polarized normally-incident radiation, the asymmetry in the front-back (F-B) scattering in the Mini-Mott will be observed. Since photoemission intensities are modulated by the projection of the vector potential of the incident radiation onto the momentum operator, it is also desirable to change the angle of incidence for linear polarized radiation to identify the symmetry of the initial state. In part (D), the magnetization vector for both the perpendicular and in-plane cases will result in asymmetries for both F-B and L-R channels. The direction of magnetization is simply determined from the direction of the applied field which creates an asymmetry reversal.

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14. For synchrotron radiation from a bending magnet or undulator with polarization in the orbital plane of the electrons (horizontal and transverse to the beam), s-polarization is only possible for normal incidence. For off-normal radiation, the radiation is considered to be p-polarized since the A-vector is parallel to the plane of incidence.

Figure Captions

Figure 1. Schematic diagram of the electron optics (side view). (A) Rotating entrance lens assembly. (B) Transfer lens. (C) 11-inch diameter hemispherical analyzer. (D) Transfer lens. (E) Spin-resolving Mini-Mott detector.

Figure 2. Illustration of possible experimental geometries (top view). (A) "Double polarization." (B) Perpendicular and (C) in-plane magnetized ferromagnetic samples with s-polarized radiation. (D) Excitation with p-polarized radiation.

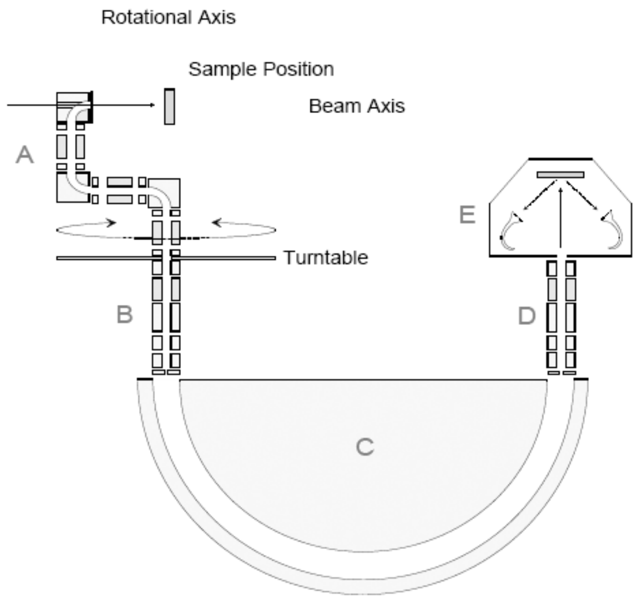
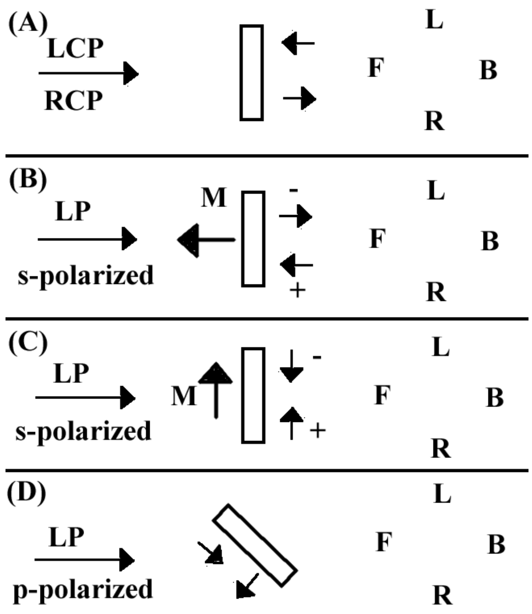

Rotational Axis
Sample Position
Beam Axis
A
E
Turntable
B
D
C

Figure 1.


(A)
LCP
RCP
L
F
B
R
(B)
LP
s-polarized
M
-
+
L
F
B
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(C)
LP
s-polarized
M
-
+
L
F
B
R
(D)
LP
p-polarized
L
F
B
R

Figure 2.