High-Resolution X-ray Photoemission Electron Microscopy at the Advanced Light Source

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X-ray Photoemission Electron Microscopy (X-PEEM) is a full-field imaging technique where the sample is illuminated by an x-ray beam and the photoemitted electrons are imaged on a screen by means of an electron optics. It therefore combines two well-established materials analysis techniques - photoemission electron microscopy (PEEM) and x-ray spectroscopy such as near edge x-ray absorption fine structure (NEXAFS) spectroscopy. This combination opens a wide field of new applications in materials research and has proven to be a powerful tool to investigate simultaneously topological, elemental, chemical state, and magnetic properties of surfaces, thin films, and multilayers at high spatial resolution. A new X-PEEM installed at the bend magnet beamline 7.3.1.1 at the ALS is designed for a spatial resolution of 20 nm and is currently under commissioning.

INTRODUCTION

Near Edge X-ray Absorption Fine Structure (NEXAFS) spectroscopy is an established technique to study materials properties such as elemental composition, chemical bonding, and molecular orientation [1]. It is based on the availability of X-ray radiation of tunable wavelength produced by a synchrotron. Utilizing the polarization of the synchrotron radiation, one can perform x-ray magnetic dichroism (XMD) spectroscopy to investigate the magnetic structure and atomic magnetic properties of magnetically ordered materials [2]. Third-generation sources of high-brilliance synchrotron radiation make it possible to combine effectively spectroscopic methods like NEXAFS and high spatial resolution microscopy techniques. The latter can be achieved either by scanning techniques or by parallel image acquisition. In scanning x-ray microscopy an x-ray optics focuses the beam and a detector senses photons or electrons as the x-ray spot moves across the sample surface (or as the sample rasters through a fixed x-ray spot). The lateral resolution is therefore determined by the size of the x-ray spot. In contrast, x-ray photoemission electron microscopy (X-PEEM) is a full-field imaging technique where the sample is illuminated by an x-ray spot focused to a size of the largest field of view considered. In this case the resolution is determined by the aberrations of the electron-optical imaging system consisting of two or more electrostatic lenses. In addition, due to a parallel collection of information an imaging technique is inherently fast and allows the study of time dependent processes at video rates. At present, there are several spectromicroscopes in operation at synchrotron radiation facilities. The highest spatial resolution so far reported for such an instrument is 40 nm and has been achieved by the Clausthal group at BESSY I [3]. The new X-PEEM installed at the bend magnet beamline 7.3.1.1 at the ALS is designed for a spatial resolution of 20 nm and is currently under commissioning. An even more advanced instrument equipped with an electrostatic hyperbolic-field mirror that allows correction of spherical and chromatic aberrations simultaneously is in the design phase. The use of an aberration–correcting mirror has the potential for pushing the spatial-resolution limit of the X-PEEM to a few nm. Another UHV spectromicroscope called SMART with a similar spatial resolution is under construction for a soft x-ray undulator beamline at BESSY II [4].

EXPERIMENTAL SET-UP

Figure 1 shows the schematic layout of the spectromicroscopy beamline 7.3.1.1 at the ALS. The spherical grating monochromator provides soft x-rays in a spectral range from 260 eV to 1500 eV with a resolving power of $E/\Delta E$ = 1800 and $3x10^{12}$ photons/s/0.1%BW at 800 eV. The use of a bend magnet gives the choice of linearly or circularly polarized radiation. The x-ray beam is focused on the sample with a spot size of 30 µm x 30 µm. The objective lens is of conical shape allowing the sample to be illuminated by the x-ray beam at an angle of about 30 degrees (*c.f.*, Fig. 2). The photoemitted electrons are accelerated by the immersion objective lens and form an intermediate image with a magnification of m = 10. In order to reduce spherical and chromatic aberrations the microscope is designed for a rather high accelerating voltage of 30 kV. Three corrector elements are incorporate into the microscope column to accommodate for lens imperfections and misalignment of the individual components. In order to correct for astigmatism an octopole stigmator is located in the back focal plane of the objective lens. Two hexapole deflectors, one located right behind the stigmator, the second one at the back focal plane of the intermediate lens (*cf.*, Fig. 2), correct for beam deflection caused by misalignment of the lens elements. The back focal plane of the objective lens would also be a well-suited place for an angle-limiting aperture which has an electron energy filtering effect and therefore reduces the chromatic aberrations. Since the stigmator/deflector arrangement does not leave enough space, a transfer lens with a magnification of unity is added to form another (conjugate) back focal plane where the aperture can be located. However, the insertion of an aperture reduces the transmittance of the microscope to typically 5% (for an aperture diameter of 12 µm). The intermediate and projective lenses form a magnified image on a phosphorous screen from where the image is transferred to a slow-scan CCD camera using a fiber-optics coupling with a 1:2 taper. The calculated resolution limit is about 20 nm.

OUTLOOK

The new X-PEEM at BL 7.3.1.1 is not only equipped with a surface science preparation chamber and load-lock system for fast sample transfers, it has also incorporated an electron-beam evaporator for *in situ* deposition. The sample manipulator is equipped with an electron-beam heating system for temperatures up to 1500 °C. Therefore the combination of x-ray spectroscopy and high spatial resolution photoemission electron microscopy together with surface science sample preparation capabilities make this X-PEEM a very versatile instrument in the field of materials science. Major future applications will be magnetic domain imaging of magnetic recording materials, elemental and chemical bonding contrast imaging of hard disk coatings and sliders, and the study of dewetting and decomposition phenomena of thin polymer blends and bilayers.

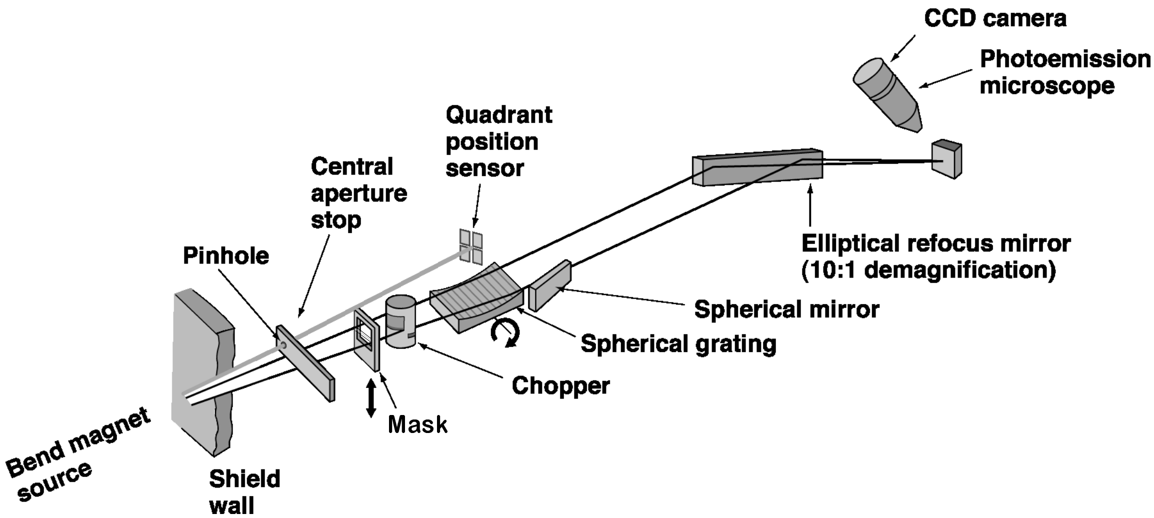

FIGURE 1: Schematic layout of the spectromicroscopy beamline 7.3.1.1 at the ALS.

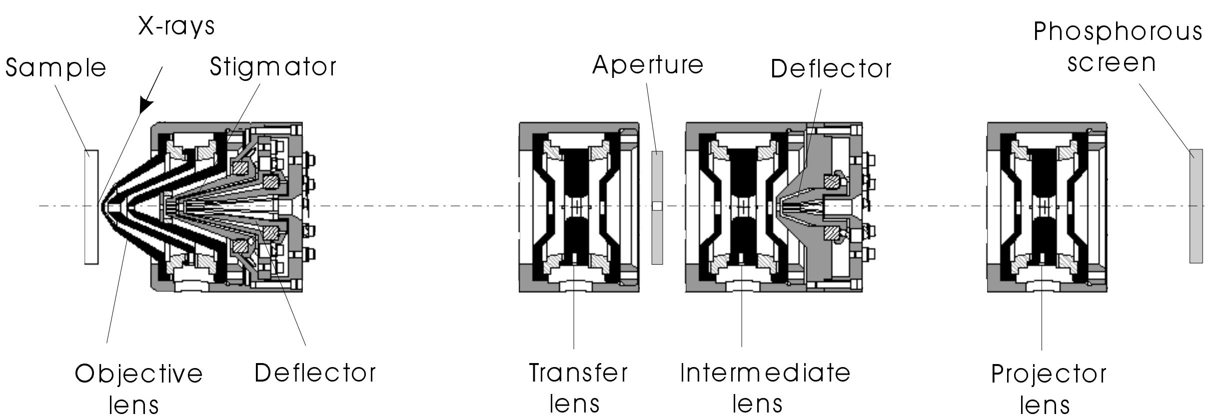

FIGURE 2: Schematic layout of the new X-PEEM electron optics. The lens design was adapted from an existing x-ray transmission microscope [5].

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