

PHOTOELECTRON SPECTROSCOPY — OPPORTUNITIES AND CHALLENGES

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The progress in key technologies is intimately connected to the synthesis and understanding of new materials as well as the refinement and optimization of known material systems. Together with improving the functionality of a material system, however, often its structural, chemical and electronic complexity increases. A major challenge in understanding the properties of these complicated layered structures is the determination of the chemical state, electronic or magnetic state/structure in a layer or at an interface. With respect to the investigation of nanosized objects, a breakthrough has been achieved by establishing total yield x-ray photoemission electron microscopy (XPEEM) as a very versatile nanoscopy technique for static and dynamic problems [1,2].

Even more information on the details of the electronic states is provided by direct photoelectrons. In order to discriminate these in the yield spectrum an energy-filtering in XPEEM must be used [3-5]. We will focus on a two specific approaches, which we have established during the last two years. The first one combines an electrostatic PEEM column with a double-hemispherical energy analyser to permit laterally resolved XPS studies. This instrument has been coined “NanoESCA” and has been recently installed at the soft x-ray nanospectroscopy beamline at the storage ring facility Elettra (Italy) [6]. The second approach employs an aberration-corrected LEEM/PEEM instrument [5], which has been installed at the Jlich soft x-ray beamline at BESSY-II (Berlin).

The NanoESCA instrument — The system at ELETTRA features a novel electrostatic lens system with 30 kV extraction voltage, a double-hemispherical energy filter [7], a single-event counting detector unit, and a 5-axis sample manipulator with liquid helium cooling. The system provides two operation modes: (i) spatially resolved photoelectron imaging with a lateral resolution of < 100 nm, and (ii) mapping of the photoelectron angular distribution (k-space microscopy). It is also equipped with a surface science preparation chamber and a load-lock system to introduce samples without breaking the UHV.

Soft XPS Imaging — A first test has been carried out on a grating-type sample with variable line

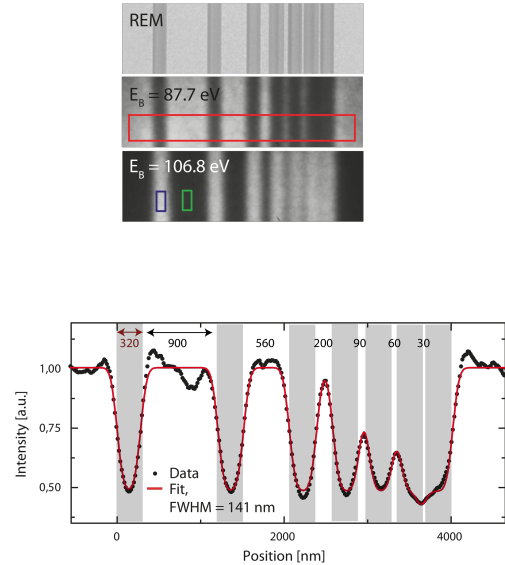


Figure 1: Soft x-ray photoemission nanoscopy from a grating-type Au/SiO₂/Si sample (photon energy 200 eV).

spacing. For this purpose, 320 nm wide grooves have been milled by a focused ion beam into a Au film on a SiO₂/Si template, leaving behind Au lines with widths ranging from 900 nm down to 30 nm. The data (Fig. 1) show a scanning electron microscope image compared to XPS images on the Au 4f ($E_B = 87.8$ eV) and Si 2p ($E_B = 106.8$ eV) photoemission lines. In the Si 2p line we can discern an image contrast even down to the smallest Au line. A quantitative analysis of the lateral resolution is obtained on the basis of a line scan across the Au pattern reproduced in the bottom part of the figure. This line scan is the average of horizontal pixel lines in the Au 4f image. Fitting the experimental data by a set of Lorentzians and step functions yields a value of 141 nm for the FWHM of the Lorentzians. This is a measure of the lateral resolution obtained in this experiment.

Hard XPS Imaging — Fig. 2 displays the first result obtained by hard x-ray nanoscopy from a Au/Si checkerboard calibration sample. The photon energy has been 6.5 keV. Because of the low photoemission cross section in hard x-ray photoemission and the resulting low signal levels, we operated the microscope with the largest available contrast

aperture ($500 \mu\text{m}$), which limits the lateral resolution. The data demonstrate clearly that element-selective imaging on the Au 4f and Si 2p is feasible. In both cases the kinetic energy of the photoelectrons is more than 6.4 keV. The inelastic mean free path of the photoelectrons at this kinetic energy is about 10 nm, which is still well below the thickness of the Au layer. Therefore, we see a clear contrast inversion in the images when switching between the Au 4f and Si 2p photoemission signal. A further analysis of the images reveals a lateral resolution of about 450 nm, which agrees well with the expectations from electron-optical simulations for the chosen contrast aperture. We could also demonstrate that it is possible to image the interface in a Au/SrTiO₃ layer structure through the 10 nm thick Au top layer.

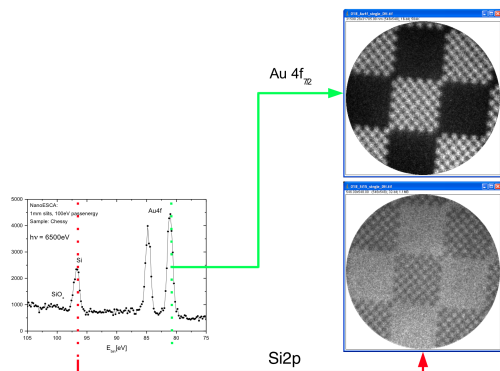


Figure 2: Hard x-ray photoemission nanoscopy from a checkerboard Au/SiO₂/Si sample (photon energy 6500 eV).

Reciprocal Space Mapping — By using a diffraction lens behind the objective the angular distribution rather than the spatial distribution of the photoelectrons is mapped onto the image detector. By choosing appropriate kinetic energies of the photoelectrons this allows one to image a cut through the energy distribution curves. In particular, if the kinetic energy corresponds to the Fermi energy E_F we are able to directly map the Fermi surface. This is demonstrated in Fig. 3 for a Ag(111) surface. The photon energy of $h\nu = 21.2 \text{ eV}$ gives access to the first Brillouin zone (BZ) which is seen as a circle around the center of the image. In addition, small parts of the neighboring BZs are seen. The angular field of view is not limited by the microscope settings but the maximum k-vector transfer at this photon energy. This becomes obvious by increasing the photon energy to $h\nu = 40.8 \text{ eV}$. Now the wave vector transfer allows one to probe a larger portion of the nearest neighbor BZs and to access also the next nearest neighbor BZs. This operation mode has also been employed to study topological insulators.

We will also report on first experiences with the aberration corrected PEEM/LEEM sys-

tem at the synchrotron radiation source BESSY in Berlin. This instrument is mainly dedicated to time-resolved studies of magnetization dynamics with an emphasis on high lateral resolution rather than spectroscopic capabilities.

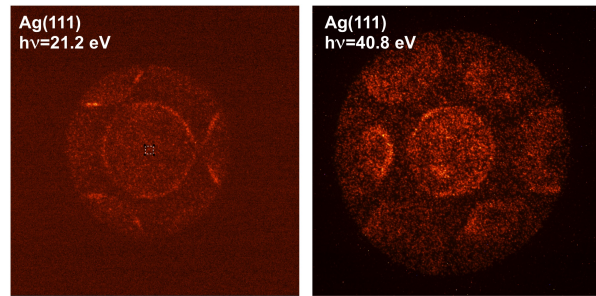


Figure 3: Fermi surface mapping from a Ag(111) surface at two different photon energies.

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