Polarization dependent photoelectron emission

with high lateral resolution

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Application Note

Introduction

In high resolution photoelectron spectroscopy (XPS/UPS), the distribution of the kinetic energy E_{kin} of the detected photoelectrons can be used to probe the composition of the surface and its valence band structure, i.e. the electronic binding energy. In these experiments, the lateral resolution is typically poorer than 10 µm because the detectors are optimized for high resolution in the energy space rather than for high spatial resolution. On the other hand, a photoelectron emission microscope (PEEM) is optimized for imaging at superior lateral resolution down to 10 nm. By using an imaging energy filter – in the case of the presented experimental setup a set of two micro-grids providing a retarding field – one can even acquire spectroscopic information on a 50 nm scale. Moreover, the PEEM setup in Linz allows studying the dependence of the local photoelectron yield on the polarization of the incident UV light. In particular, the real-time capabilities of the PEEM are used to study the evolution of the anisotropy of metal surfaces during the deposition of organic dye molecules.
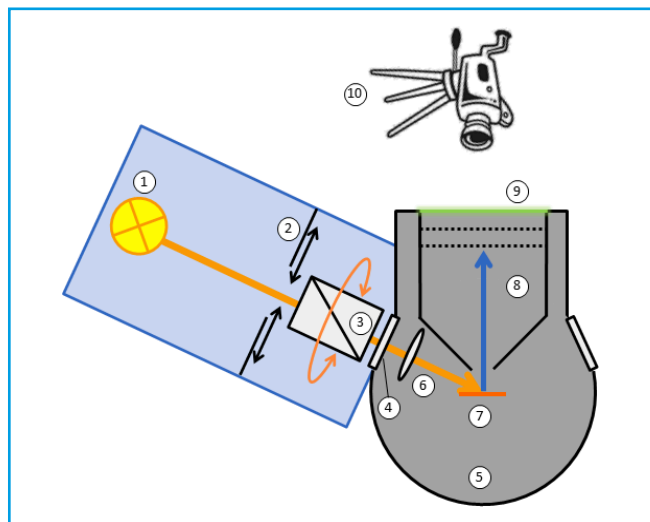
optical setup. An electronic shutter (2) is used to reduce the photon dose between measurements. A Glan prism (3) serves as linear polarizer. The prism can be rotated precisely by a stepper motor. Parts (1) to (3) are incorporated in a box which can be flooded with nitrogen gas to prevent the absorption of the UV light by oxygen in the ambient.

Via a view port (4) the light is coupled into the ultra-high vacuum chamber. The base pressure here is usually below 5×10^{-10} mbar. The light is focused by an in vacuo lens (6) onto the sample to increase the local photon flux. The emitted photoelectrons are imaged through the electrostatic lens system (8) of the PEEM onto the micro channel plate (MCP) array and the fluorescence screen (9).

The images are acquired with an Andor Neo sCMOS camera operated in 16 bit (dual gain) mode with a typical acquisition time of 1 s. To image the fluorescence screen on the sCMOS sensor a Schneider Kreuznach Componon 12 lens system is used. To prevent stray light from entering the detector, screen and macro lens are incorporated into a lightproof box.

PEEM (microscope and energy filter), shutter and rotation stage of the polarizer are controlled by a custom made LabView program. To synchronize the acquisition of the images with the rotation of the polarizer, TTL pulses are used to trigger the camera. The TTL pulses are generated by an FTDI USB to serial converter (EVAL232R).

The data are acquired with the Andor Solis software. The complex data processing, including background subtraction, flat field correction and image registration, were carried out afterwards by means of the free image processing software ImageJ (Rasband 2012). The software also allows extracting the electron yield of individual pixels as a function of the angle of the polarizer prism.

Figure 1 Schematic of the experimental setup to probe the polarization dependence of the photoelectron emission

Experimental Setup

Figure 1 shows a schematic of the setup used to acquire the local electron yield as a function of the polarization direction of the incident light. A high flux UV lamp (1) is used as photon source. Either a Hg (4.9 eV) or a D_2 lamp (up to 10.8 eV) can be mounted on the

Results and discussion

At typical PEEM image of a polycrystalline silver foil is depicted in Figure 2 (a). Before inserting the sample into the ultra-high vacuum chamber the surface was mechanically polished. To remove contaminations of the sample surface it was bombarded with Ar-ions and

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afterwards annealed at 660 K. The field of view of Figure 2 (a) is about 145 μm. On the image, different grains can be distinguished due to their different work functions: The higher the work function, the lower the electron yield. The fundamental contrast of a Photoelectron Emission Microscope (PEEM) is based on Einstein's description of the outer photoelectric effect (Einstein 1905):

$$E_{kin} = E_{bin} + \theta + h\nu$$

Whether an electron can by emitted upon excitation by a photon thus depends on the work function θ and the photon energy $h\nu$. Therefore, different materials and even different facets of the same crystalline material exhibit different electron yield (intensity).

Besides this contrast mechanism also the local topography affects the electron yield leading to an accentuation of the grain boundaries.

Figure 2 (b) depicts the polarization dependent emission yield for two individual pixels. In this case, the data was acquired in steps of 5° of the polarizer angle a. The expected traces can be described by the following function:

$$electron\ yield = O + A \cdot \sin^2(\omega\ a + a_0)$$

Whereas the offset O and the amplitude A are very similar for both points, the phase shift a_0 is not. For the two points a phase difference of $\Delta a_0 \approx 12°$ was found. The phase shift a_0 obviously depends on the local crystalline structure of the sample. This can be explained by the local optical and electronic anisotropy of the surface.

By processing the whole image in the same way on a pixel by pixel basis, one can derive a spatially resolved image of the phase shift a_0 as depicted in Figure 2 (c). Likewise, the amplitude A and the offset O can be plotted (not shown here). All three parameters can thus be used to visualize the anisotropy of the surface. The images nicely demonstrate that areas which appear homogenous in the PEEM image may consist of different grains with different crystallographic orientations.

Conclusion

The use of polarized light adds a new contrast mechanism to photoemission electron microscopy (PEEM). Whereas in a conventional PEEM image the contrast is provided by information about the work function and the topography, the phase shift of the polarization dependent emission yield is an independent parameter related to the anisotropy of the sample.

The data reported here clearly demonstrate that only a camera with a high dynamic range and low noise is suitable for such polarization dependent image acquisition. The local intensity changes by a factor of two which is much larger than the variation of the intensities of different pixels within one image. In this respect, the Andor Neo is a an improvement to the formerly used 12 bit CCD camera and an affordable alternative to more sophisticated ultra-low cooled EMCCD cameras.
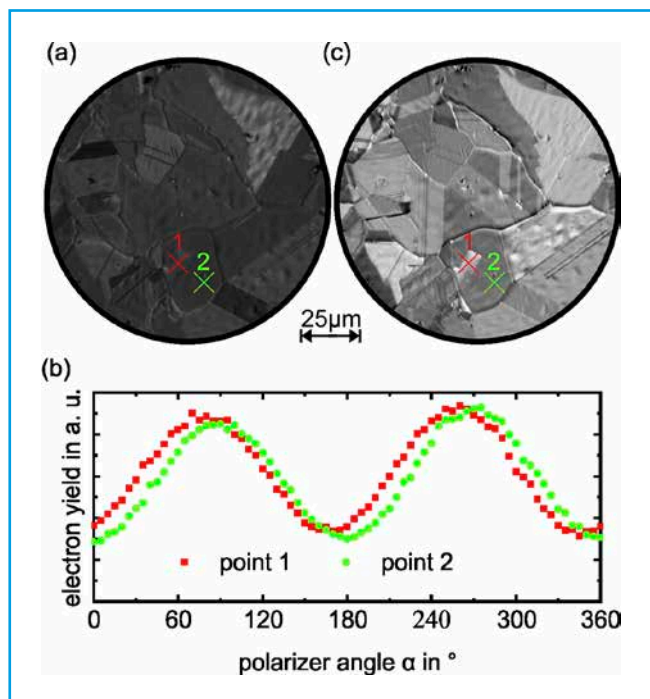

Figure 2 (a) PEEM image of a polycrystalline silver surface corresponding to the total photoelectron yield with the unpolarized light of a Hg lamp, (b) local electron yield optained from two points of the series as a function of the polarizer angle in steps of 5°. The phase shift between the two points of the surface is 12°. The spatial variation of the phase across the is plotted in (c).

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The actual experiments in Linz do not make use of the high acquisition speed of the camera, but gain from the cooling of the sensor and, therefore, from its signal to noise ratio. In addition, we improve the signal to noise ratio by binning of the pixels as the effective optical resolution is limited by the MCP array of the electron optics. As the experiments already include an amplification step (MCP array), algorithms based on "photon/electron counting" implemented on the camera might be used to improve the dynamic range while at the same time the data which have to be transferred to and processed by the PC would be reduced significantly.

References

Einstein, Albert. „Über einen die Erzeugung und Verwandlung des Lichtes betreffenden heuristischen Gesichtspunkt." 1905: 132-148.

Rasband, Wayne. „ImageJ." Available for download at http://rsbweb.nih.gov/ij/, 07 16, 2012.

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