

Synchrotron radiation project report

PEEM

Johan Eriksson
joher@ifm.liu.se

INTRODUCTION

The photoelectron emission microscopy (PEEM) technique was first published in 1933¹ by E. Brüche [1]. It is quite unique since it enables several different properties of the studied samples to be imaged, e.g. topographic, chemical composition and magnetic properties. The first systems built consisted simple electrostatic optics giving a very moderate magnification. For excitation UV light from a Hg-lamp was used. The technology improved, with apertures, better electron optics and synchrotron light sources lateral resolutions of $<10\text{nm}$ have been achieved [2].

THE MICROSCOPE

PEEM works by analyzing electrons which are emitted from the studied sample upon excitation by photons. As a photoemission technique it is special in that it has spatial resolution. This resolution is obtained by keeping the emitted electron beam under strict control during its passage through the electron optics and channelplate. Fig. 1 shows the components of the PEEM, from the sample to where the output image is produced. A strong potential difference is applied between the sample and the objective lens element². As a result electrons are accelerated into the optics stage. Several magnetic and/or electrostatic lenses are then used on the electron beam. Eventually they end up on an multi-channelplate which multiply the electron count and eject the electrons onto a fluorescent screen. By adjusting the settings of the projector lens stage one can choose to image the real space plane och the reciprocal space plane. One can thus by simply changing

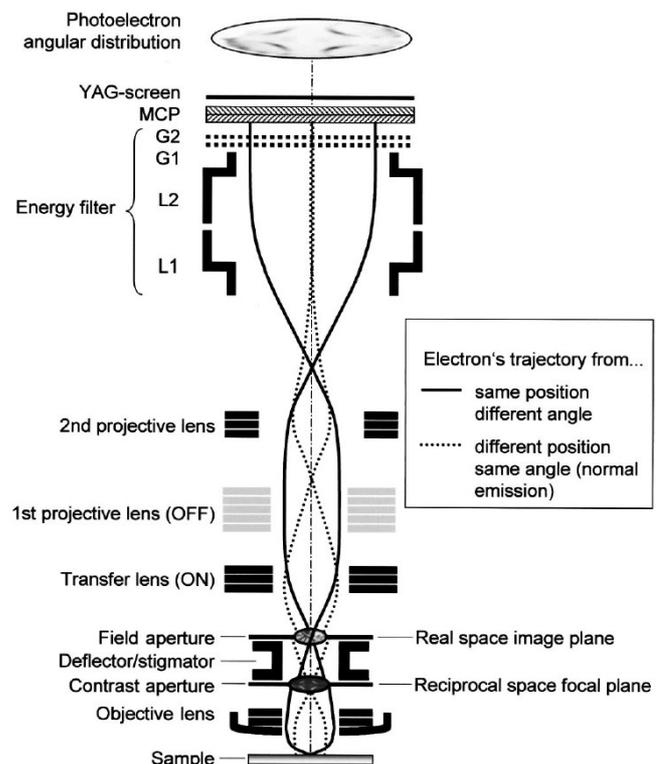


Fig. 1: Components of a PEEM. From [3].

the voltages in the projector stage switch between real space and reciprocal space view of the sample. Some microscopes have energy filters to image only part of the electron yield which may be useful at such high photon energies that secondary electrons may dominate the total electron yield. The difference in energy of the electrons can give rise to chromatic aberration, to minimize this correcting elements can be inserted in the optics.

1 Same year as Ruska built the first scanning electron microscope.

2 In principle this means that the sample is part of an immersive objective lens.

EXPERIMENTAL DETAIL

There are some restrictions to what samples can be used in PEEM. Due to the very strong field between the sample and the objective lens element, the sample must be very flat. Protrusions will alter the objective field and can distort the image of the surrounding area. Sharp features can also give rise to such high field strengths that there is a risk of electrical field breakdown.

PEEM is a surface sensitive technique and there are several reasons why it is so. The incoming photons are attenuated according to the Beer-Lambert law in the sample. Depending on material in the sample and the photon energy this penetration depth will vary. The mean free path of the electrons will also play a major role, it is also, indirectly through the kinetic energy, dependent on the photon energy. All the depth information is eventually overlaid in the images and strong contrast originating from a volume near the surface will make it difficult to discern the much weaker contrast from deeper layers. Using hard x-ray PEEM information depths of more than 50nm has been demonstrated [4]. That is about one order of magnitude higher than in soft x-ray PEEM [4].

The instrument is capable of operating at a wide sample temperature range. Thus, e.g. different stages of growth, such as nucleation and precipitation can be studied. Vacuum conditions must however be quite good because of the long electron trajectories through the optics.

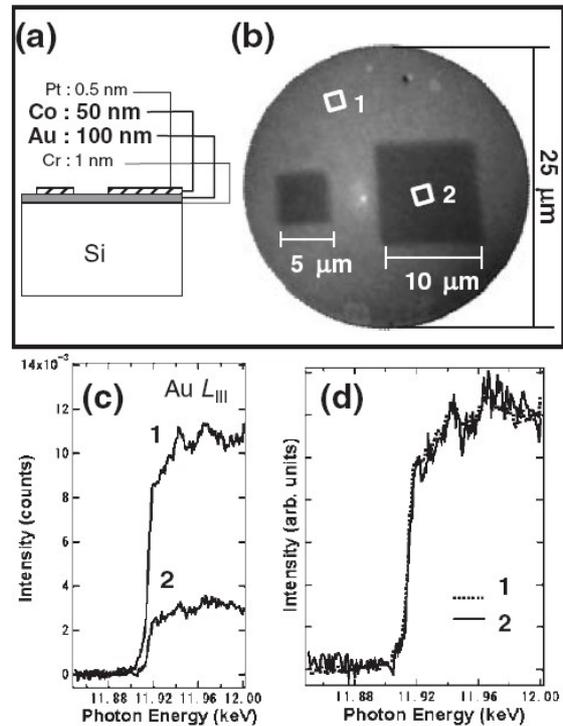


Fig. 2: Hard x-ray (11.85keV) PEEM image showing intensity from a bare Au layer (1) and a Au layer under 50nm of Co (2). From [4]

A PEEM system bears some similarities with Low energy electron microscopy (LEEM) and (Mirror electron microscopy (MEM) -system. All the techniques can be found on some instruments. In LEEM and MEM the excitation side is different from PEEM. The photon source is exchanged for an electron source.

SOME RESULTS FROM PEEM

- Chemical composition.

Different elements have different electronic energy levels. At these energy levels the elements exhibit a dramatic increase in photon absorption, absorption edges. By probing a material with different photon energies it is possible to determine the chemical composition of the area under the microscope. A certain element will give a higher electron yield when excited with an energy at the absorption edge. To discriminate between elements it may be useful to have an instrument equipped with an energy filter. It is then possible to look at only a certain part of the total electron yield.

- Growth and surface structure

Photoemission intensity is very surface sensitive if the photon energy is chosen properly. The universal mean free path curve has a minimum of a few Å near a 50eV. Using this it is possible to resolve height differences with mono layer precision by examining contrast differences in the

images.

- Magnetic properties.

By using circularly polarized light domains on the sample with different magnetization will give different electron yield. This can be used to investigate the effect of the smaller and smaller magnetic domains on modern hard disks and also serve as a useful tool in the emerging field of spintronics.

- Fermi surface mapping

The possibility of probing reciprocal space using PEEM can be utilized for making images of the Fermi surface similar to what is possible with angle resolved photoemission spectroscopy (ARPES). On the screen an area in reciprocal space in the plane of the sample surface is seen. The perpendicular \mathbf{k} -component is determined by the kinetic energy of the electrons. Thus, by taking a stack of images with different photon energy one can obtain a 3D (k_x, k_y, k_z) map of the Fermi surface.

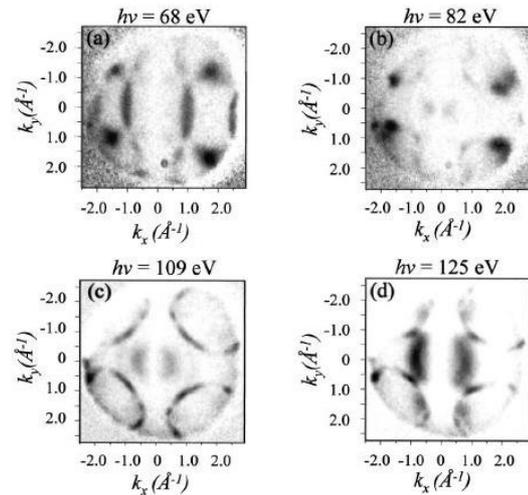


Fig. 3: Reciprocal images showing the Fermi surface. From [3]

References

- [1] E. Brüche, Z. Phys. 86, 448 (1933).
- [2] J. M. Garguilo, thesis, North Carolina State University.
- [3] M. Kotsugi, et al., Rev. Sci. Instr. 74, 2754 (2003).
- [4] T. Wakita, Jpn. J. Appl. Phys. 45, 1886 (2006).