FOCUS PEEM

Photo Emission Electron Microscope

- 20 nm Lateral Resolution
- Easy to Operate
- Real-Time Imaging
- Surface Sensitive Microscopy
- Chemical Mapping
- Local Spectroscopy
- Compatible with MULTIPROBE UHV Systems
The Bolt-On PEEM
An Ease of Operation Concept
Photoemission Electron Microscopy (PEEM) is an extremely powerful imaging technique, whose versatility for topographical, chemical and magnetic contrast imaging at high resolution has been demonstrated in many laboratory and synchrotron applications.

Important contributions to characterisation of magnetic devices, plasmon research, surface chemistry and high lateral resolution chemical analysis in combination with synchrotron radiation, investigation of time resolved processes and k-Space imaging are only a few examples of active PEEM based research.

In contrast to a Scanning Electron Microscope (SEM), PEEM directly images surface areas emitting photoelectrons in real-time, without scanning. Electron emission from surfaces can be caused in various ways - by photon irradiation excitation, thermally, via electron/ion bombardment or by field emission.

Over the years the FOCUS PEEM has been continually improved in performance and usability. The PEEM together with the dedicated high stability integrated sample stage (IS) and various available energy filters follows a modular concept easy to upgrade. In addition software assisted operation ensures time efficient and secure PEEM operation even on challenging samples. With more than 50 units in the market the FOCUS IS-PEEM is a powerful surface analysis tool featuring:

- Convenient software assistance
- Easy integration into UHV Systems
- Uncompromised stability with IS-Stage
- k-space imaging
- Key strengths in spectroscopy:
  - Time-of-flight analysis
  - High-pass imaging energy filter
  - Micro-analyzer
  - Aberration compensated band pass filter

Platinum wires, 8 nm thick, 50 nm wide (smallest dimension) on a 20 nm thick Titanium oxide film on 100 nm Silicon oxide. The sample shows an array of 17 wires starting with contact areas of approximately 40 µm which contact a wire line, each wire has a width of 50 nm. A small FoV (field of view) of 9 µm shows that the 50 nm wires and contacting area can be clearly resolved.
The Modular Concept

FOCUS PEEM Features

The FOCUS PEEM BA is the basic version of the PEEM instrument series. It is a bolt-on instrument which can be easily integrated in vacuum chambers. It is the heart of all extended PEEM instruments.

For high performance PEEM operation a rigid and compatible sample manipulator is required in order to avoid the influence of mechanical vibrations.

The FOCUS PEEM features a three-lens, fully electrostatic electron column consisting of a tetrode objective lens - an immersion lens in which the sample is part of the lens- and a distortion-free double projective lens.

Combined with the adjustable Contrast Aperture and the Stigmator/Deflector module, the electron optics is capable of a resolution below 20 nm.
FOCUS IS-PEEM

The integral sample stage of the IS-PEEM guarantees ultimate stability for optimal resolution avoiding any possible relative movement of sample and objective by mechanical integration of the sample into the objective. This is of particular importance for applications with long acquisition times, which can be obtained without compromising the resolution. The piezo-electrically driven IS-stage provides precise positioning of the sample within an area of 8 x 8 mm with an accuracy of 100 nm.

The IS-stage may be retrofitted to the FOCUS PEEM BA. The sample plates (molybdenum or stainless steel) for the IS-PEEM are compatible with Omicron’s range of instruments for multi-technique surface science and UHV SPM. A dedicated bolt-on PEEM chamber allows for easy combination with other surface science applications.

Position Readout
The optional position readout allows the user to navigate on their samples, and reposition automatically on any interesting feature. In addition the position readout also allows for automated large area mapping.

Variable Temperature
The IS-stage can be equipped with an electron bombardment sample heating facility (sample at ground potential) for temperatures up to 2300 K, allowing the imaging of thermally induced phase transitions or even thermally emitted electrons during heating. Optionally, the IS-stage may be fitted with sample cooling down to about 100 K. In addition a dedicated low temperature sample stage for operation down to 25 K is available on request.

Iris Aperture
The optional variable iris aperture enables reduction of the PEEM’s field of view down to a well defined micro-spot as small as 1 μm in diameter. The iris aperture is essential for micro-spot analysis. The aperture size is continuously adjustable via a rotary feedthrough. Precise positioning of the micro-spot for local analysis, e.g. using X-ray absorption spectroscopy (μ-XPS/μ-UPS), is accomplished by either the stigmator/deflector or the integrated sample stage of the IS-PEEM. The iris aperture is also required for k-space imaging.

Energy Filtering
The FOCUS PEEM is especially well-suited for spectroscopic PEEM applications. Depending on the application it can be equipped with various energy filters such as the Imaging High-Pass Energy Filter (IEF), Time-of-Flight (TOF) detectors or the aberration compensated band pass for highest transmission spectroscopic PEEM imaging. Various filter concepts will be discussed on the following pages.

k-Space Lens
Imaging of the angular distribution of the emitted electrons instead of the ‘real’ image is possible by switching from real space to k-space imaging. In the FOCUS PEEM, this is achieved with the optional transfer lens. Additionally the transfer lens allows for very large area imaging >1000 μm. In combination with the TOF, IEF or NanoESCA the instrument allows for k-space mapping with a very large acceptance angle of ± 90 degrees in the UPS regime. Moreover single shot Fermi surface imaging e.g. in combination with the HIS 13 VUV lab source or focussed high energy lasers becomes possible.
Time-of-Flight Energy Filter

The Time-of-Flight (TOF) imaging energy filter is ideally suited for energy filtered low intensity applications with electrons in the low kinetic energy range.

Together with a time sensitive imaging Delay Line Detector (2D DLD), a dedicated drift tube and a pulsed light source, the TOF PEEM offers a unique detection system. The detector allows true single electron counting with massive parallel detection and excellent signal to noise ratio. In addition to standard energy filtered TOF PEEM experiments the detector also allows for time dependent studies with an overall time resolution of < 250 ps.

Lower drift energies inside the drift tube allow higher energy resolution. The special design of the FOCUS PEEM allows for operation at extremely low drift energies (10 eV) while maintaining the lateral resolution of the instrument. The TOF PEEM has achieved an energy resolution of down to 50 meV.

A prerequisite for any kind of TOF experiment is a pulsed light source such as pulsed lasers or synchrotrons. The TOF detector may be retrofitted to existing FOCUS (IS-)PEEMs.

(A) Integral of a time (energy) filtered image stack of Ag microstructures on a Si substrate and (B) local TOF spectra, taken with a 400 nm pulsed diode laser (60 psec/40 MHz) excitation. Note that the intensity in the nanosized 'hot spot' is enhanced by a factor of 200 and the energy onset of the electrons from 'hot spot' area is about 0.6 eV lower than that from the smooth area.
7 Time (Energy) filtered images with a time separation of 1.2 ns; electrons excited at the sample surface are separated by the TOF PEEM in time. Electrons with high kinetic energy will hit the detector earlier than electrons with low kinetic energy. Therefore each individual time slice corresponds to different electron energies.
Spectral Unmixing is an algorithm integrated in the PEEM imaging software that performs a least error fit of up to four prototype spectra (here two: green and red) to each pixel in the spectral image series (see below). It identifies the correlation of the image with the 'finger print' of the related spectra. The weights of each prototype spectrum are displayed in separate images. The right hand image represents the mixed weights of the two prototype spectra shown above colored in green and red within the image.

The incorporation of energy filtering into the FOCUS PEEM yields improved performance and opens up new application possibilities. The retarding imaging energy filter (IEF) acts as a high pass filter for the full image.

Setting the energy filter to a specific electron energy facilitates element specific mapping with increased contrast. The IEF is a dedicated energy filter for all applications with good photoelectron yield. The IEF effectively reduces the chromatic aberration, i.e. the energy spread of the electrons contributing to the formation of the image. This is of particular importance for chemical and magnetic imaging in synchrotron applications, where the achievable resolution is reduced due to the 'unfocused' contribution of high energy electrons.

The IEF can also be used for micro spectroscopy analysis. XPS and AES spectra up to a kinetic energy of 1600 eV and with energy resolution well below 100 meV can be obtained in areas smaller than 1 μm. Using laboratory excitation sources (threshold photoemission microscopy), imaging at specific work functions with energy filtering yields a strongly enhanced contrast.

The raw data are collected as images at a certain cut-off energy with a CCD camera. The spectra are extracted from the images, also allowing integration over selected areas within the image. The IEF may be retrofitted to existing FOCUS (IS-)PEEMs.

Spectral Unmixing is an algorithm integrated in the PEEM imaging software that performs a least error fit of up to four prototype spectra (here two: green and red) to each pixel in the spectral image series (see below). It identifies the correlation of the image with the 'finger print' of the related spectra. The weights of each prototype spectrum are displayed in separate images. The right hand image represents the mixed weights of the two prototype spectra shown above colored in green and red within the image.
Energy filtered image series with an increment of 110 meV per image.
Sample: Polycrystalline Copper.
Excitation: 4.9 eV (Hg arc lamp).
PEEM with Micro-Analyser

The FOCUS PEEM micro-analyser combines real-time surface microscopy with local chemical analysis using microspot electron spectroscopy (kinetic energy up to 1600 eV) at an energy resolution down to 80 meV and below.

Laboratory and synchrotron sources (soft-XPS, UPS, AES) may be used. The PEEM acts as a high performance entrance lens with variable magnification for the 50 mm hemispherical analyser.

The variable lateral resolution can be selected down to 1 μm spot size with the Iris aperture. In contrast to the imaging energy filter, the micro-analyser features dedicated small spot spectroscopy performance with high energy resolution and discrete pass energies between 1 eV and 80 eV. The micro-analyser may be retrofitted to existing FOCUS (IS-)PEEMs.

NanoESCA* features ultimate spectroscopic performance for PEEM imaging in the UPS and XPS regimes.

The NanoESCA consists of a PEEM and an imaging energy analyser. The dedicated aberration compensated imaging energy band pass filter allows for ultimate spectroscopic PEEM performance. Highest transmission and optimum energy resolution are key features of the NanoESCA. The complete image is transmitted through the double-pass analyser. Aberrations introduced by the first hemispherical analyser are fully compensated to the 3rd order by the second hemispherical analyser - a patented arrangement allowing for excellent laterally-resolved chemical state photoelectron spectroscopy results with optimum signal to noise ratio. Imaging XPS and UPS features a kinetic energy range from 0 eV to 1600 eV at < 200 meV energy resolution (imaging mode: achieved 110 meV). In addition a (optional) small spot spectroscopy mode is available. The small spot spectroscopy mode provides precise quantification as well as the detection of localised contaminants. In addition the non-filtered PEEM mode allows for high resolution imaging: 30 nm achieved. A dedicated monochromated small spot laboratory Al Kα X-ray source is optionally available. The unique combination of the high flux density X-ray source and NanoESCA’s excellent transmission allows for unsurpassed XPS core level imaging with achieved lateral resolution of below 500 nm in convenient laboratory conditions. The optional transfer lens allows for µ-ARPES with full control over the analysed area by real space PEEM imaging (momentum microscope).

The NanoESCA is an imaging analyser derived from an electrostatic photoemission electron microscope (PEEM) column, combined with the aberration compensated double hemispherical analyser. Three operating modes are available: • direct non-energy-filtered PEEM, • energy filtered imaging, • small spot, area selected spectroscopy.
Bolt-On Concept / System Integration

The FOCUS IS-PEEM strictly follows the flexible ‘bolt-on’ concept - a flange mounted instrument without the need for a dedicated PEEM UHV system.

With the integrated sample stage (IS) directly attached to the lens system the FOCUS IS-PEEM allows for uncompromised mechanical stability when attached to a UHV system. It is compatible with Omicron sample transfer and other surface analysis instruments. The modularity of the FOCUS PEEM with the PEEM’s unique contrast mechanisms and high resolution fits perfectly with the wide range of modular Omicron solutions.

The bolt-on concept at a glance:
- Flange mounted instrument
- Simple integration into UHV systems
- Integrated sample stage for minimum vibration
- Integrated mu-metal shield
- Easy to upgrade and maintain
- Sample handling compatible with many other Omicron instruments

The PEEM Probe is a UHV system with a small food print tailored for the needs of daily PEEM work. It provides ports for various excitation sources, evaporators, a sputter cleaning source and sample heating. In addition the system is also designed to house a dedicated LHe cooled sample stage for PEEM operation below 30 K.

A perfect match: MULTIPROBE S housing the FOCUS IS-PEEM with IEF and the VT SPM. The PEEM allows quantitative work function analysis while VT SPM provides atomic resolution in all AFM and STM modes.

A UHV system for MBE growth, PEEM and SPM work. Combination of a dedicated MBE growth system MULTIPROBE MBE housing various evaporators and RHEED with an FOCUS IS-PEEM and a VT SPM for in-situ characterisation of thin films.
Together with the recently developed software ‘ProPEEM’, the whole PEEM instrument becomes a very easy to operate surface analysis tool.

The quality of the results usually depends not only on the imaging and analytical properties of the PEEM column but also on the ease of operation and the user skill level. ProPEEM - based on extensive electron optical simulations - is an intuitive graphical user interface which provides convenient assistance to the operator. The user has direct control of the microscopes magnification which can be continuously adjusted from 1 : 20x to 1 : 7200x in a standard FOCUS PEEM. With recently implemented features such as pre-focusing, automated detector intensity adaptation and a simplified stigmation correction, ProPEEM allows for time efficient and convenient PEEM operation.

The Intelli Control is a state-of-the-art fully computer controlled modular electronics. The front panel’s joystick allows for sample navigation in addition to all relevant parameters being monitored.

Screenshots of ‘ProPEEM’ software. Left: User mode allows software assisted operation. The magnification can be selected by choosing the field of view see (insert and example images on a test pattern). Right: aperture positioning screen.
Results

The PEEM with IEF is able to image the angular distribution of photo electrons. Shown here: Cu (111) excited with $h\nu = 185$ eV (VERA-beamline, ANKA, cooperation FOCUS/IFP). An image stack has been taken between $E_B = 8.5$ eV and $E_B = -2.5$ eV. The upper left image represents the $k_x/k_y$ map at an energy $E_B = 2.1$ eV. The right one reflects the cross section along an $E/k_y$ plane, the lower one shows an $E/k_x$ plane along the symmetry axis.

Orbital mapping of carbon-$\pi^*$: Element specific imaging of a (100) diamond film reveals the presence of graphite.

Overview of the direction of the magnetic interlayer coupling in an FeNi-FeMn-Co single-crystalline trilayer on Cu(001). The Co thickness increases from left to right up to 8 ML. The thickness of the top FeNi layer is 6 ML. Layer-resolved magnetic domain images are acquired by XMCD-PEEM at the Fe and Co L₃ absorption edges.

Molecules: para-sexiphenyl (6P)
Nucleation and 3D growth of para-sexiphenyl nanostructures. Still image from PEEM growth video, after deposition of 6 ML, demonstrating the well ordered (203) oriented crystalline needles that form when 6P self-assembles on Cu(110) at 140 °C (scale bar 10 µm). Needles: dark lines, wetting monolayer: bright areas between needles.

Nanoscopic field control. a) The photoelectron distribution is displayed on a 1.13 µm x 1.13 µm square for p-polarised excitation of the star-shaped nanostructure with laser pulses at 790 nm. This distribution acts as a reference for the optimisation experiments with complex polarisation-modulated laser pulses. The color scale bar represents the photoemission yield in arbitrary units. The white arrow indicates the projected direction of incidence k (incidence angle 65°). The nanostructure positions are marked by white circles, and the regions of interest A and B by yellow squares. b) Adaptive optimisation of the A/B photoemission ratio leads to increased (red) and decreased (blue) contrast of electron yields from the upper and lower regions as compared to unshaped laser pulses recorded as a reference (black). For comparison, the range of contrast variation achieved by non-adaptive single-parameter scanning of the spectrally constant phase offset between the two pulse-shaper polarisation components (green arrow) is smaller and does not provide the same degree of control. c) The experimental PEEM image after adaptive A/B maximisation using complex polarisation-shaped laser pulses shows predominant emission from the upper region. d) Photoemission after A/B minimisation is concentrated in the lower region. e, f, The optimal laser pulses as experimentally characterised display complex temporal electric-field evolution for the maximisation (e) and minimisation (f) objectives. E1 and E2 indicate the two field components that are phase-modulated in the polarisation pulse shaper in the first and second LCD layer, respectively. They are at ±45° angles with respect to p-polarisation. The overall time window shown is 2 ps. g, h, The simulated two-photon photoemission pattern for the experimental pulse shapes in the cases of A/B maximisation g) and minimisation h) qualitatively confirm the experimentally demonstrated nano-optical field control. 4

Organic Transistors: graphite and spin-coated P3HT. In order to optimize organic field effect transistors (OFETs), the characterisation of active-layer surfaces in terms of their roughness, chemical composition and distribution of surface potentials is important. Hg PEEM images of a source-drain structure made of graphite and spin-coated P3HT. (A) Channel (dark area) and graphite electrodes, covered with P3HT. (B) Channel and graphite electrodes, partially covered with P3HT. The brighter areas represent zones without P3HT and lower surface potentials respectively. 5

Specifications

The FOCUS PEEM BA (with external manipulator):
Same specifications as IS-PEEM, except for
Lateral resolution: 80 nm

The FOCUS IS-PEEM
Lateral resolution: 40 nm
Magnification: 1:20 - 1:7 200
Field of view: 2.5 µm – 900 µm
With k-Space lens: 2.5 µm - 1800 µm

Integrated sample stage:
Motor: piezo / X and Y movement: ± 4.0 mm
Extractor voltage range: 100 - 15 000 V

Software:
- Auto Focus when magnification is changed
- Simplified stigmation / deflection correction
- Safety Guard for MCP
- Aperture finding mode
- Manual operation mode

Camera:
- Slow scan CCD camera
- Peltier cooled slow scan CCD camera for low intensity applications

Options:
- Absolute position read out
- Iris field aperture
- Extended extractor range 100–30 000 V
- Heating (PBN) temperature range:
  (room temp.) RT – 600 K
- (E-Beam) temperature range:
  (room temp.) RT – 2 300 K
- High temperature: flash heating only
- Cooling
  - LN₂, cooling with bath cryostat
  - LHe flow cryostat (on request)
- Excitation sources
  - Hg-lamp
  - O₂-lamp
  - HIS 13 (He-Discharge lamp) see related brochure

Energy filtering

Imaging Energy Filter
- Type: Imaging High Pass Filter
- Modes: filtered / non filtered
- Energy resolution: 100 meV
- Full software support

Time-of-Flight
- Type: Imaging TOF
- Modes: filtered / non filtered / time resolved
- Energy resolution: 100 meV
- Full software support

Micro-Analyzer
- Type: area integral
- Modes: PEEM / spectroscopy
- Energy resolution: 100 meV
- Full software support

NanoESCA
- Type: Imaging Band Pass
For details please refer NanoESCA brochure