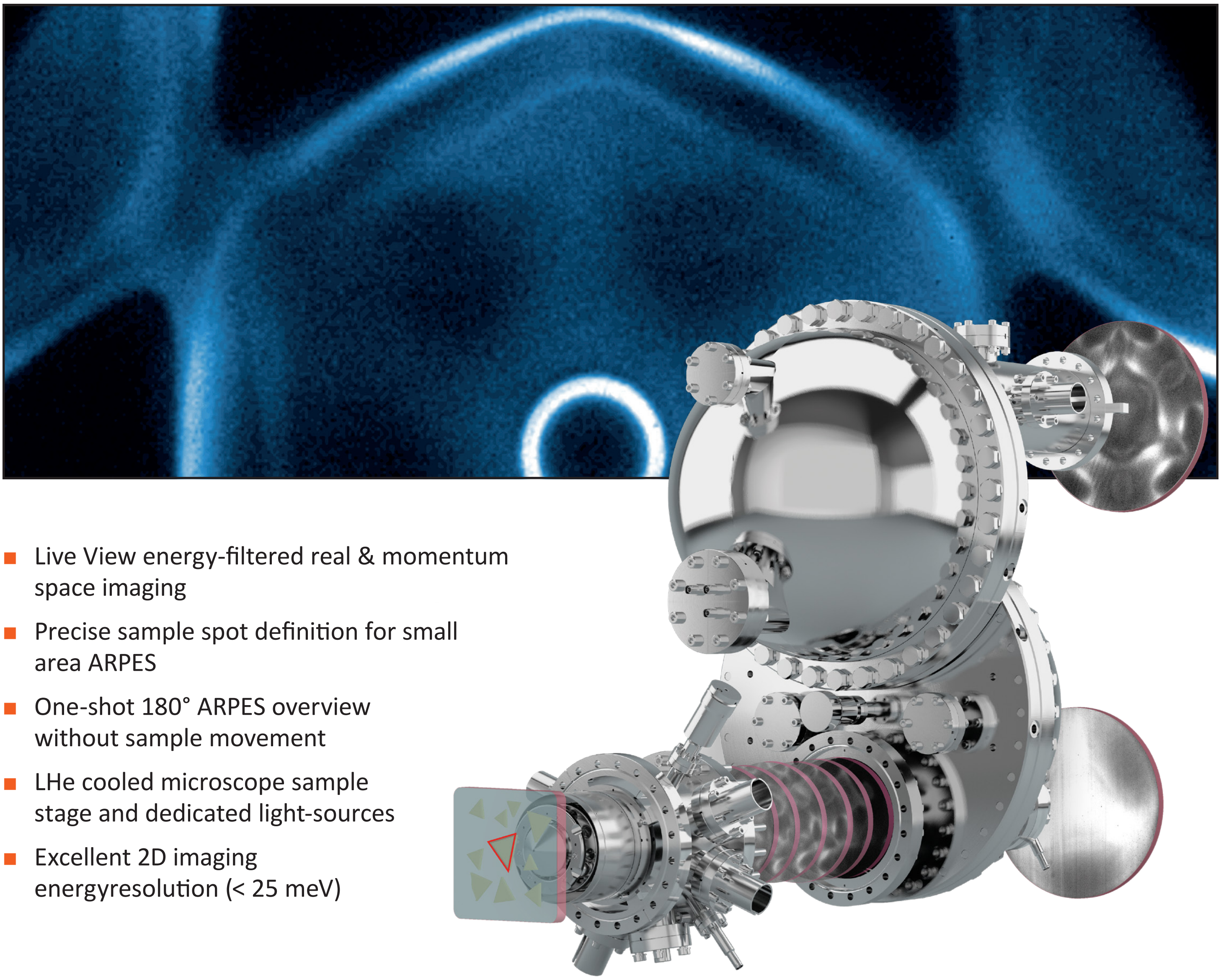
NANOESCA

Next-generation photoemission tool for real- and momentum-space microscopy



- Live View energy-filtered real & momentum space imaging
- Precise sample spot definition for small area ARPES
- One-shot 180° ARPES overview without sample movement
- LHe cooled microscope sample stage and dedicated light-sources
- Excellent 2D imaging energyresolution (< 25 meV)

From microscopy to band-structure mapping

Photoemission has a history as one of the leading techniques in material and surface science. In the last decade, 2D k-space imaging or "Momentum Microscopy" has become one of the latest and most promising developments in this field. It allows insight into the electron band-structure of novel material systems, unveiling useful effects that can have a strong impact in future information technology. In combination with real-space imaging it is the ideal tool to make new materials applicable to next-generation devices.

Band structure is the key to understanding the working principals of nearly all solid-state devices (transistors, microprocessors, LEDs, solar cells, etc.). New material classes including graphene, topological insulators, and transition metal dichalcogenides (TMDs) are examined for their use in future electronic devices. TMDs, especially, are chemically versatile and thus predestined to tune their electronic structure for various applications. Momentum Microcopy provides a fast band structure mapping, which becomes essential for device engineering in the future.

Momentum Microscopy describes the combination of a photoemission electron microscope (PEEM) with an imaging band-pass energy filter (see Figure 1). For kinetic electron energies up to 40 eV the microscope collects all photoelectrons emitted into the complete solid angle above the sample surface. For a discrete energy (selected by the band-pass filter) it forms an image of the photoelectron distribution as a function of the lateral momentum (kx, ky). For example, it is possible to see a full Brillouin zone for certain energies, (e.g. the Fermi surface) in one shot. In live-view mode, it is possible to navigate through the band structure, zoom into details or adjust apertures. By scanning a range of energy filtered momentum maps, one directly gets a 3D data cube (lateral electron momentum vs. electron binding energy) which represents the accessible electronic band structure of the material under investigation (see Figure 2c).

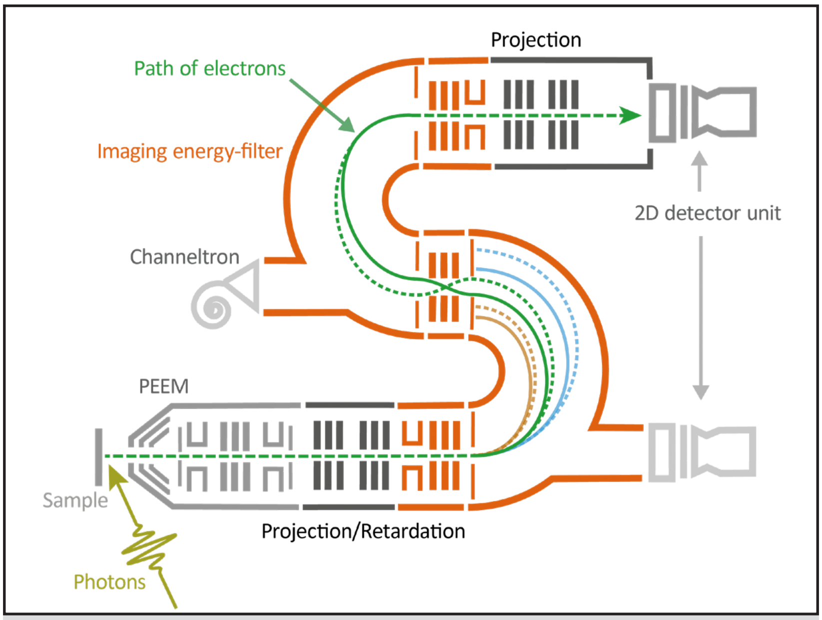


Figure 1: Sketch of the NanoESCA concept. The PEEM image is projected onto the entrance of the imaging energy-filter. The first hemisphere separates different kinetic electron energies, while the second hemisphere is used to compensate the (spherical) aberrations induced by the first one.

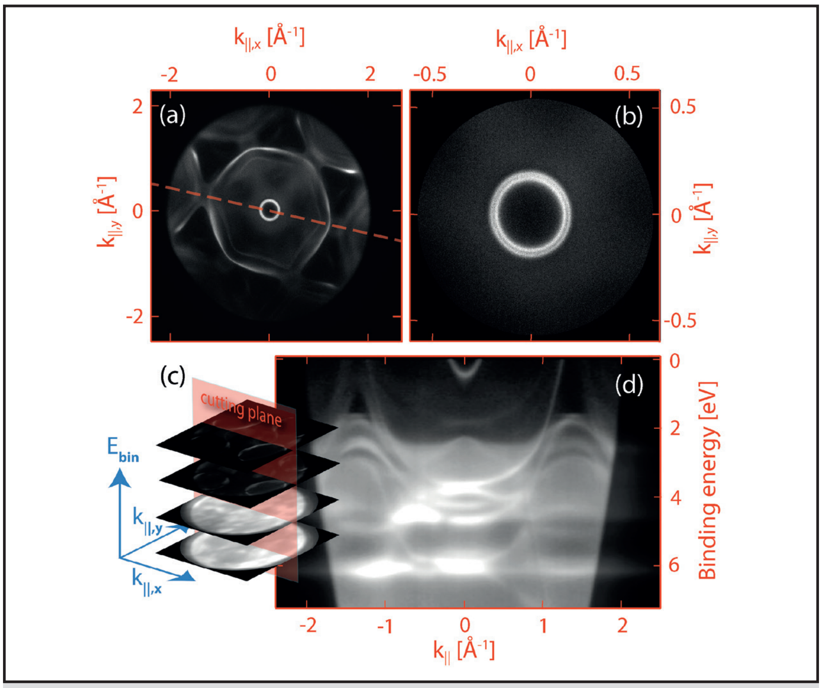


Figure 2: Momentum Microscopy on a clean Au (111) surface. The overview momentum map of the Fermi energy (a) shows more than a full Brillouin zone, while the zoomed in map resolves features like the Rashba surface splitting. Acquiring these momentum map for all energies in the valence band leads to a 3D data stack (c), which can be cut in any high symmetry direction (d) to study the band structure of a material. The shown measurements were performed in a laboratory setup with a HIS 14 VUV light source (photon energy 21,18 eV (He I)) and a liquid He cooled manipulator (T = 30 K).
The energy analyzer was set to 50 meV energy resolution.

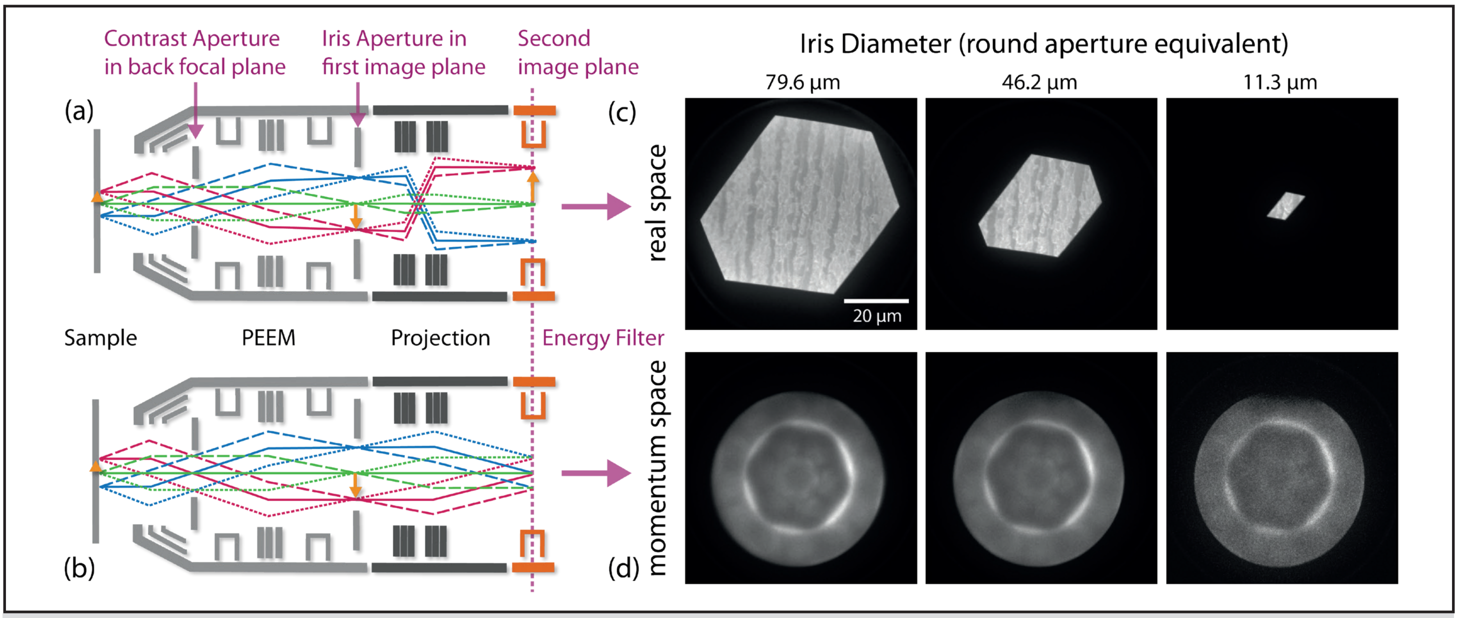


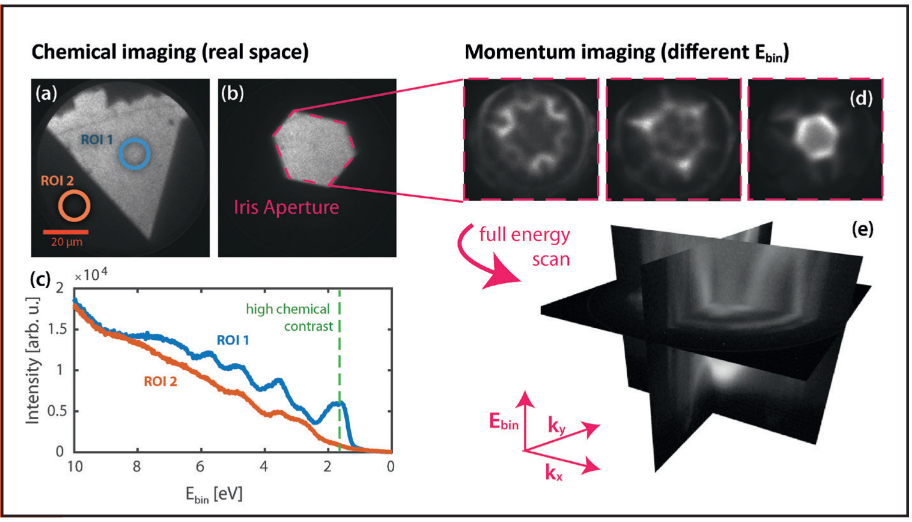
Figure 3: The PEEM column can be easily changed between real-space imaging (a) and momentum-space imaging (b) by adjusting the projection lenses. The electron trajectories of both settings are equal up to the first imaging plane to allow a reliable positioning of the apertures. The iris-aperture in the first image plane can for example be used to define a small spot on the sample surface (c), from which the momentum-space data can be acquired (d). All shown images were acquired in a 10 s exposure time, the signal being also intense enough for live imaging (500 ms exposure time). The shown images were acquired on a monolayer of graphene on SiC.

This extended PEEM lens is designed to easily switch between real-space imaging and momentum-space imaging by switching the projection lens settings (see Figure 3).
At the same time, the electron trajectories in both modes are equal up to the first image plane. This implies that one can use the two different apertures integrated into the PEEM column. The first one at the back focal plane of the objective lens (contrast aperture) restricts the angular acceptance of the microscope. In real-space imaging this reduces the spherical aberration and thus enhances the resolution of the PEEM. For momentum space imaging it is typically fully open.

The second aperture is an iris-aperture. As shown in Figure 3c, it can be used to define a small emitting area on the sample (< 6 µm), from which photoelectrons are measured in momentum mode.

µ-ARPES workflow:

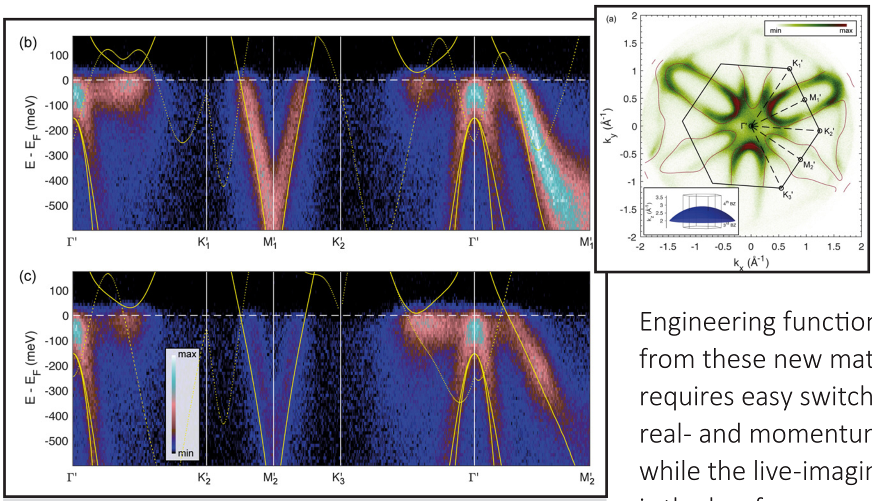
- Set energy- filter to an energy with high chemical contrast between features (c)
- Localize a feature in real-space imaging mode (a)
- Close iris aperture to isolate signal from the feature (b)
- Acquire momentum images for a range of energies (d)
- Combine image stack to a 3D band structure map (E_{bin} vs k_x, k_y) (e)



The combination of a PEEM column with an electrostatic double-hemispherical imaging energy-analyser makes the Nano-ESCA one of the most promising concepts for surface and material science of the next decade.

NanoESCA system equipped with vibration damping system, LHe cooled manipulator, HIS 14 VUV light-source and preparation chamber with pre-analysis capabilities.

The 2D mapping of the complete electron momentum distribution at the Fermi level is extremely interesting for novel materials (graphene, topological insulators, TMDs), and will play an important role in the next generation of devices.



Momentum microscopy image of the VSe$_2$ Fermi level (Insert). The full energy resolved data cube was acquired to study the band-structure along various high symmetry axis (b,c).

Courtesy of J. Laverock, University of Bristol, GB

Engineering functional devices from these new material systems requires easy switching between real- and momentum space, while the live-imaging ability is the key for an easy and controlled workflow.

Technical Data

NanoESCA System:
Stainless steel chamber with mu-metal liner, NanoESCA analyzer, HIS 14 VUV source, mercury UV-source, LHe 4-ax microscope manipulator **

Property	**Specification**
Energy resolution, analyzer*	< 25 meV (15 meV achieved)
Energy range	0-200 eV (up to 10 keV optional)
Momentum resolution, analyzer	< 0.02 Å^{-1}
Momentum resolved range	± 2.5 Å^{-1}
equivalent angular range	± 90° (full solid angle)
lateral resolution	< 40 nm
real-space field of view	6...800 µm
Magnetic shielded analysis chamber	Yes
Base pressure, analysis chamber	< 1x10^{-10} mBar
VUV photon flux density	Up to 1 x 10^{13} ph/s/mm^2
VUV beam spot size	< 300 µm
VUV photon line-width	< 2 meV (He I)
Laser/synchrotron port	Available
Manipulator axis, motorized	x, y, z, azimuthal
x/y precision	< 3 µm
Manipulator temperature range	< 40 K...600 K
MISTRAL System Control	Yes
ProNanoESCA Measurement Software	Yes
Event Counting	Yes

Options:
A wide range of options allow for tailoring the system to the specific needs of individual reasearch. For example:

Light sources:

HIS 14 HD mono:	monochromatized VUV source
Monochromatized x-ray sources:	Al K$_\alpha$, 200 µm focus, for chemical imaging
Manipulators IS-stage:	Piezo driven x/y stage
Nano-ESCA extensions:	Channeltron detector behind first hemisphere drift tube extension for PEEM exit
Extended energy range:	0...1600 eV (for x-ray excitation)
S-CMOS camera:	75 frames/s
HAXPEEM energy range:	> 10 keV

Normal incidence mirror:	For laser experiments
System extensions preparation chamber:	Available
Damping legs:	Available

* Component specification, total performance depends on system configuration. Please contact us for details.

** This set-up is an example configuration. Please contact us for your individual configuration.

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