Components for Surface Analysis

PHOIBOS 150 WAL

Hemispherical Energy Analyzer with Wide Angle Lens

- State-of-the-art ARPES with 60° Acceptance Angle
- Optimized Lens Geometry for Non-Destructive Depth Profiling
- Large Kinetic and Pass Energy Range
- High Energy and Angular Resolution
- Complete System Concept for Samples up to 12”

Analyzer

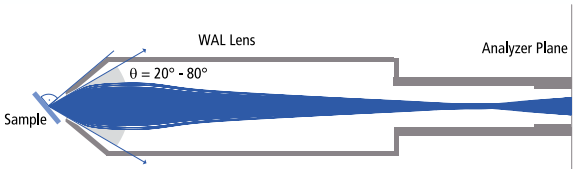
Hemispherical energy analyzers are used in photoemission spectroscopy for a wide variety of tasks, e. g. chemical analysis (ESCA), electronic structure determination (ARUPS), non-destructive depth profiling with angular resolved XPS (ARXPS), structure analysis (XPD), investigation of buried interfaces and bulk properties using hard X-ray photoemission spectroscopy (HAXPES), and in near ambient pressure conditions (NAP-PES). In all of these applications, a larger acceptance angle is favorable for different reasons:

- It increases count rate by collecting more electrons, thereby improving the signal-to-noise ratio, especially in notoriously low count rate environments like HAXPES and/or NAP-PES.
- It increases the observable volume in k-space, which is especially important when performing ARUPS at low photon energies.
- It enables angular resolved XPS for non-destructive depth profiling without rotating the sample, which is essential for large samples like 12" Si wafers.

SPECS has developed a wide angle lens (WAL), which, due to it's modular design, can be used from UPS – XPS – HAXPES, and from UHV to 25 mbar. Triggered by the needs of semiconductor technology for non-destructive depth profiling, SPECS introduced the PHOIBOS 150 WAL onto the market in 2009 and carried on with its development. In combination with a monochromated small spot X-ray source, the PHOIBOS 150 WAL offers the solution for ARPES.

Wide Angle Lens

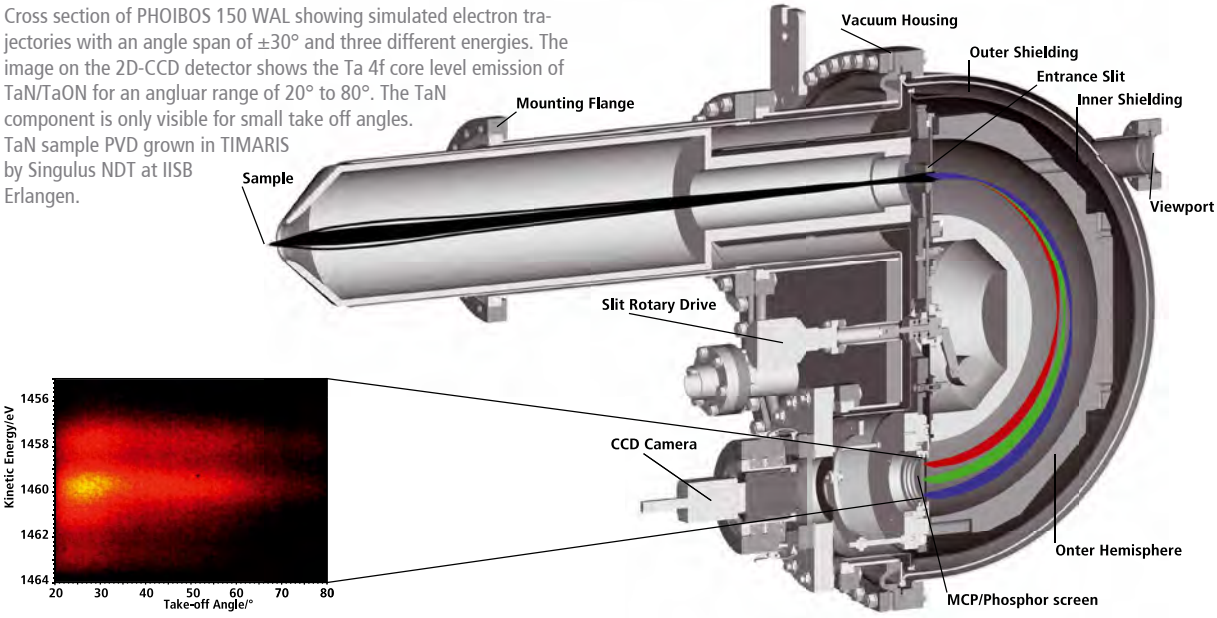
The design of the wide-angle deceleration lens uses an entrance mesh with high transparency and an optimized electrode design. The mesh is shaped to produce an image of the sample region that is analyzed at the aperture with negligible spherical aberration. The mesh lens collects electrons emitted from the sample over a cone of up to ±30°. The lens can be operated in different modes for angular studies and high transmission. All lens modes can be set electronically. The standard working distance of 27.75 mm and the ±40° conical shape of the front part of the lens provide optimum access to the sample for all kinds of excitation sources. Trajectories within an angular range of ±30° starting from different positions but with the same angle are focussed on the same location on the analyzer plane.



Simulated electron trajectories at 300 eV kinetic energy for the angular resolved mode at 30 eV pass energy and at 0.2 mm sample spot size.

The PHOIBOS 150 WAL analyzer is a true 180° hemispherical energy analyzer with 150 mm mean radius. The analyzer, the lens system, and the detector are surrounded by two layers of 2 mm thick µ-metal to screen external magnetic fields down to an uncritical level. For ultimate performance, the analyzer and the lens system are constructed entirely from nonmagnetic materials inside the µ-metal shielding.

Cross section of PHOIBOS 150 WAL showing simulated electron trajectories with an angle span of ±30° and three different energies. The image on the 2D-CCD detector shows the Ta 4f core level emission of TaN/TaON for an angluar range of 20° to 80°. The TaN component is only visible for small take off angles. TaN sample PVD grown in TIMARIS by Singulus NDT at IISB Erlangen.



Power Supply

The HSA 3500 plus is a versatile high voltage power supply. The modular design of the unit allows independent setting of all voltages via high-precision 24-bit digital-to-analog converters with an overall maximum settle time of 3 ms. Each module is equipped with a microcontroller allowing independent setting of all voltages, including diagnosis and error localization. The complete electronic package is contained in a single 19″ standard rack housing with removable cables. The power supply can be operated in FAT (Fixed Analyzer Transmission) or FRR (Fixed Retarding Ratio) mode. Both pass energy and retarding ratio can be continuously adjusted to fine-tune resolution and intensity.

With an energy span of ±3500 eV, the power supply of the PHOIBOS analyzer provides a wider energy range than most other instruments and gives access to the high kinetic energy lines. For ultra high energy resolution applications the unit can be operated in a 400 V bipolar range and a 100 V unipolar range with extremely low ripple. Step widths down to 0.125 mV are possible.

HSA 3500 plus power supply for the PHOIBOS analyzer.

These ranges guarantee extraordinary stability and low-noise, allowing ultra high resolution measurements. The power supply provides the fast and reliable CAN Bus interface and an internal microprocessor for fast and reliable processing and remote control. The temperature stability of the analyzer voltage modules are better than 1.5 ppm of the voltage span per °C.

HSA 3500 plus Modes of Operation

Range	Application	Min. Step Width	Ripple
0 ... ±3500 V	AES and XPS	7 meV	1 mV
0 ... ±1500 V	XPS	3 meV	0.5 mV
0 ... ±400 V	UPS	0.8 mV	0.25 mV
0 ... -100 V	UPS	0.125 mV	0.25 mV

Detectors

The analyzer with its modular detector concept can be equipped with different detectors according to the customer's needs. The 2D detector system (CCD or delay-line detector) uses both the energy and angular resolution for Angle Dependent XPS measurements without tilting the sample. The CCD system features a 12-bit digital CCD camera with high dynamic range. The detector design is especially optimized for the detection of low kinetic energy electrons. A 3D (one time and two lateral dimensions) delay-line detector system can be installed. The design combines high count rates with extremely high temporal resolution in one device.

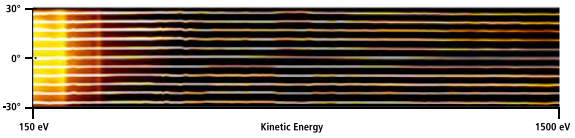
2D-CCD detector

3D-DLD detector

Performance

The angular acceptance and angular resolution of a hemispherical analyzer is usually tested during setup, where a slit array between the sample and the lens entrance is used to create a regular angular emission pattern. The slits of the array are oriented perpendicular to the entrance slit of the analyzer and create a line pattern on the detector. The width of the lines includes the contribution from the finite slit width and the finite width of the spot size amongst the angular resolution of the analyzer. Therefore, small spot excitation sources like a focussed electron source are used in such test measurements.

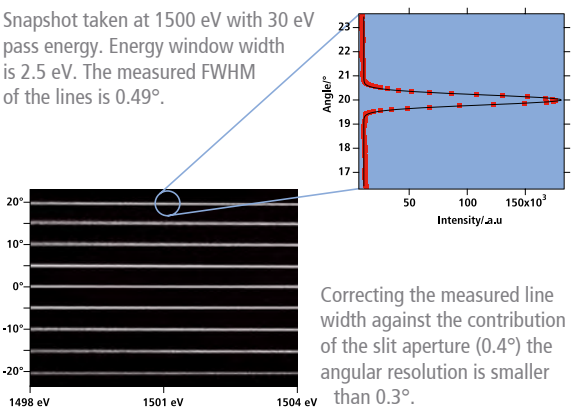
The PHOIBOS 150 WAL allows angular dependent measurements in two different modes: snapshot mode and sweep mode. In snapshot mode all voltages are kept fixed and the width of the energy window on the detector is determined by the pass energy. In sweep mode the analyzer is swept over kinetic energy with a step width smaller than the energy window on the detector. In this mode the data can be taken either with full resolution of the camera, or with a predefined number of angular channels.



Angular resolved sweep from 150 eV to 1500 eV kinetic energy with 30 eV pass energy. Angular acceptance is 60° and number of angular channels is 120. Distance between two lines is 5°.

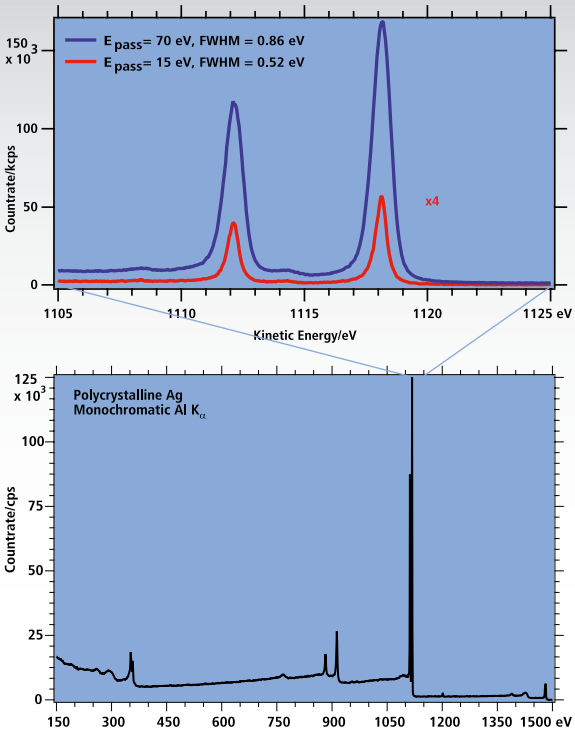
The PHOIBOS 150 WAL is able to operate in a range of retarding ratio $R = E_{kin}/E_{pass}$ of at least $4 < R < 50$ with the full angle acceptance range of ±30 degrees. A large available range in retarding ratio is of particular importance when using an X-ray source with fixed excitation energy, i.e. Al K_α.

Snapshot taken at 1500 eV with 30 eV pass energy. Energy window width is 2.5 eV. The measured FWHM of the lines is 0.49°.

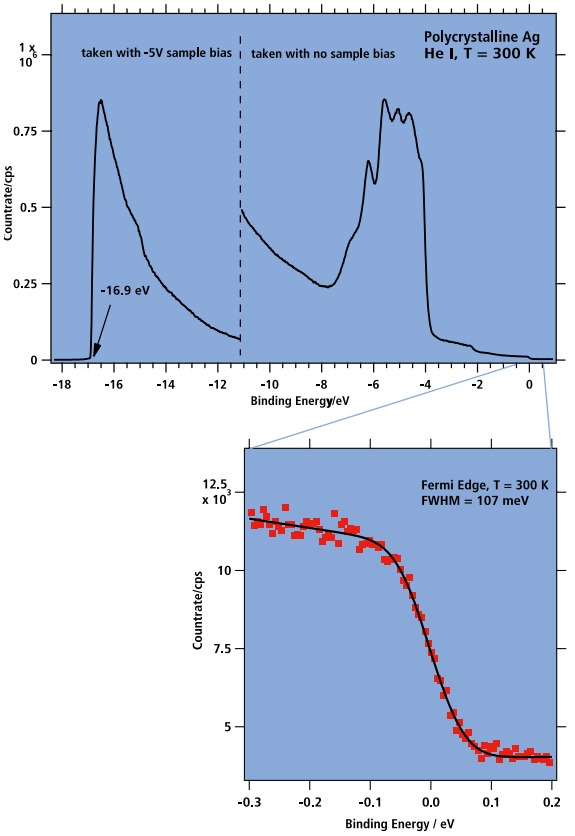


Correcting the measured line width against the contribution of the slit aperture (0.4°) the angular resolution is smaller than 0.3°.

Results



XPS spectra taken from polycrystalline Ag using a micro-FOCUS 500 monochromatic X-ray source. X-ray power is 47 W and spot size on the sample is about 200 µm.



Angle integrated UPS spectra taken from polycrystalline Ag using a non-focussed UVS 10/35 gas-discharge lamp. Spectra are excited with He I in a spot of about 1 mm. The work function of the sample is determined to 4.3 eV.

Small Spot Photon Source

High resolution photoemission measurements demand not only the highest performance electron spectrometer, but also photon sources with high flux density. Especially for angular resolved measurements the photon source spot size should be well below 1 mm, because otherwise the angular resolution is limited by the spot size broadening.

SPECS offers high performance small spot photon sources for the UV and X-ray region. In combination with the PHOIBOS 150 WAL they offer unsurpassed performance for wide angle photoemission measurments with high angular resolution. The UV sources can be equipped either directly or via a TMM monochromator with an ellipsoidal focussing capillary producing a high intensity photon spot with about 500 µm FWHM.

Small Spot UV Sources and Monochromators

The UVS 300 generates a high density plasma by guiding the electrons extracted from a hot cathode filament along the lines of a strongly inhomogeneous magnetic field towards a small discharge region (duo-plasmatron principle). The intense vacuum ultraviolet radiation is transferred from the cathode side by a capillary.

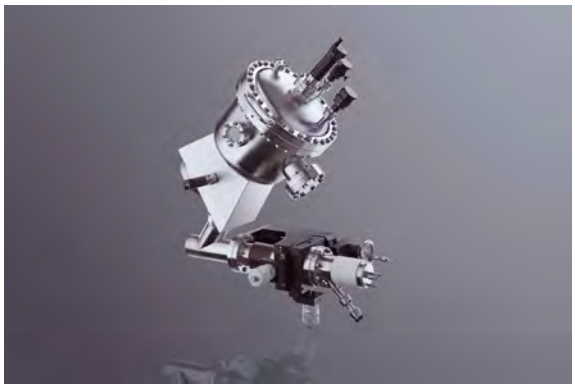
The UVLS is a filamentless microwave plasma-based UV light source. The plasma is created directly in the quartz output capillary leading to excellent coupling of the generated UV to the chamber or monochromator. This design provides long term plasma stability making the source suitable for use even with heavier gases like Ar and Xe.

The design of TMM 302 monochromator consists of a toroidal mirror in combination with a plane grating and a plane mirror. This superior design provides high transmission combined with the advantage of producing a polarized light source with a degree of polarization of 90%. The TMM 304 monochromator uses a unique cassette-based optical design to maximize the photon flux at specific user-selectable wavelengths.

UVLS + TMM 304 monochromator with ETC

Microfocus X-ray Source and Monochromator

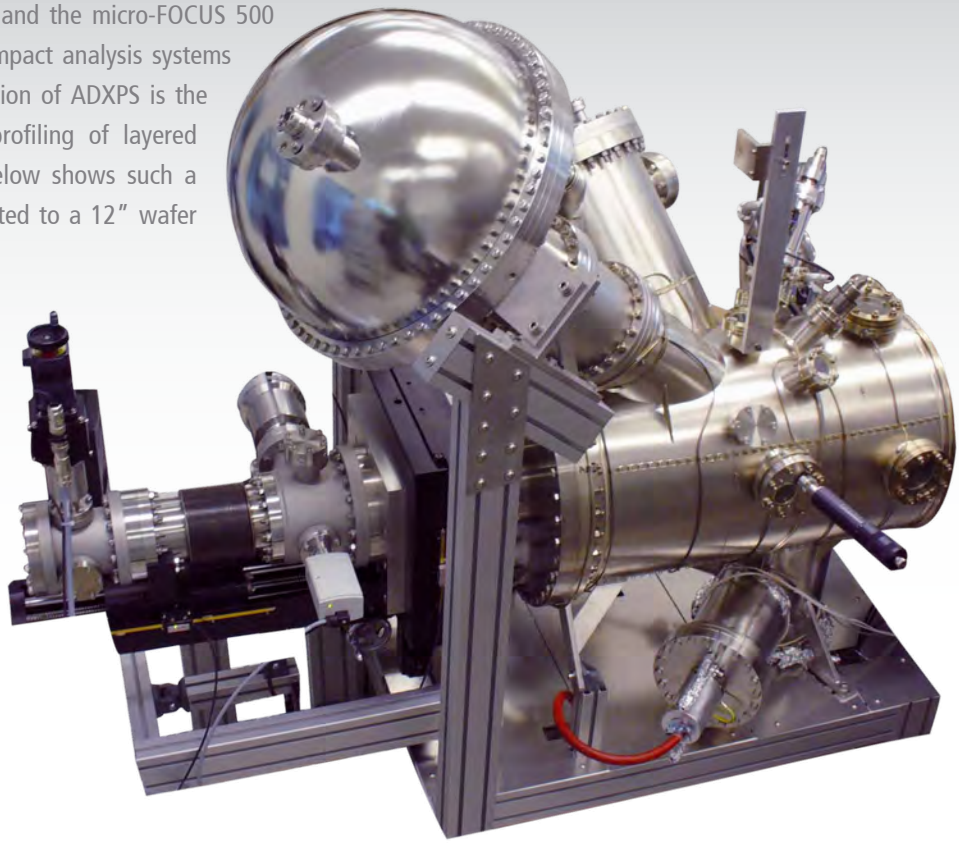
The micro-FOCUS 500 consists of a X-ray monochromator with 500 mm Rowland circle diameter and an XRMF microfocus X-ray source. The X-ray source provides Al K_α radiation in a spot smaller than 200 µm on the sample.



Micro-FOCUS 500

12" In-situ ARXPS Depth Profiling System

The PHOIBOS 150 WAL and the micro-FOCUS 500 can be integrated in compact analysis systems for ADXPS. One application of ADXPS is the non-destructive depth profiling of layered materials. The image below shows such a system, which is connected to a 12" wafer handler.



Software SpecsLab2

SpecsLab2 is the user friendly data acquisition software package which accompanies the PHOIBOS analyzer series. It enables data acquisition using a wide variety of operational modes. Some important features are:

- Angle integrated or angular resolved measurements
- Lateral resolved measurements
- 2D-measurements in sweep or snapshot mode
- Batch processing of spectra
- Ion source remote control for automated depth profiling
- Manipulator and monochromator remote control
- Remote control of the software via TCP/IP interface

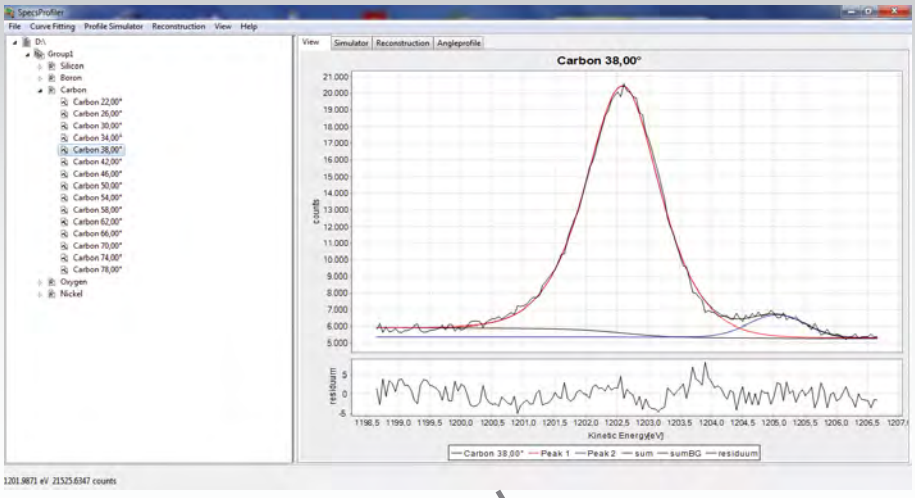
SpecsProfiler

The SpecsProfiler software is designed to extract the depth profile information from angular resolved data. The expected angular profile is simulated and compared to the measured profile. The depth profile is reconstructed using global optimization routines.

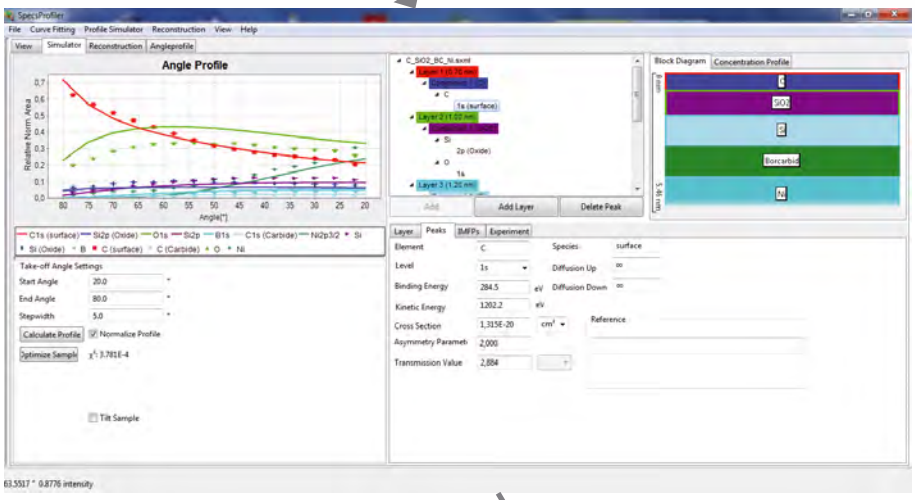
Data analysis starts with the decomposition of the spectral data in chemical components using standard peak fitting routines. The peak fitting result for a specific angle can easily be propagated to other angles.

The expected angle profile of the photoemission intensities is simulated within the sample simulator module. Extensive databases for the physical properties of elements and compounds are already included. Photoemission anisotropy and elastic scattering are taken into account.

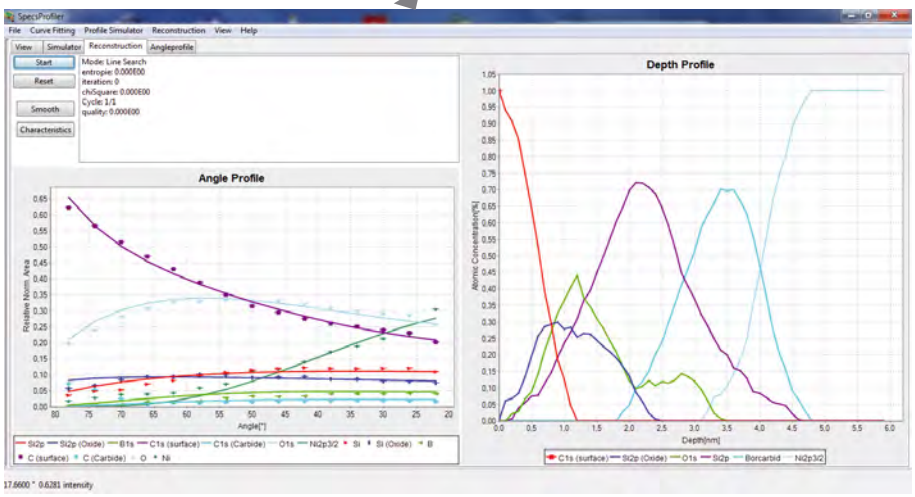
During reconstruction the expected concentration profile is varied under the control of a global optimization algorithm (Simulated Annealing or Genetic Optimization). The extraction process can be stabilized by different regularization techniques such as Maximum Entropy or Tikhonov-Phillips regularization. SpecsProfiler has proven this leading technique in an interlaboratory study of the Versailles Project on Advanced Materials and Standards (VAMAS).



Step 1: Peak fitting of core level spectra.



Step 2: Sample simulator module.



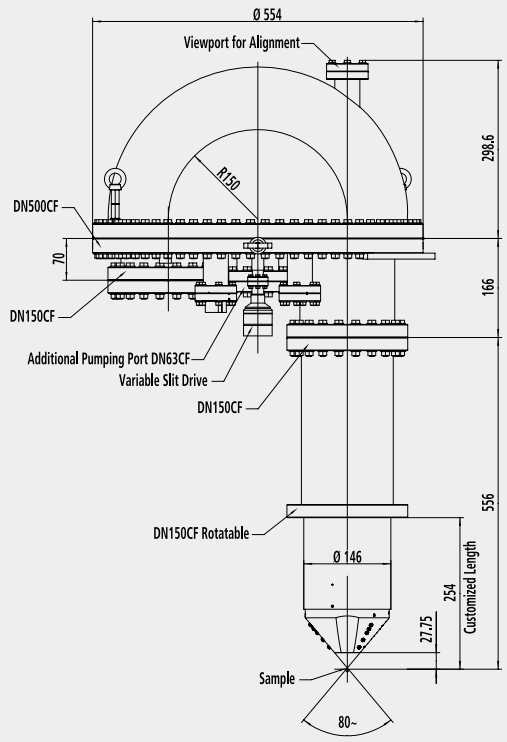
Step 3: Resulting angle and depth profile.

Data courtesy of ANNA (European Integrated Activity of Excellence an Networking for Nano and Micros-Electronics Analysis).

Technical Data

PHOIBOS 150 WAL	
Acceptance Angle (Angular Resolved Mode)	60°
Angular Resolution	< 0.5° (200 µm spot size)
Maximum Tilt Angle	50°
Kinetic Energy Range	5 - 3500 eV
Pass Energy Range	1 - 200 eV
Energy Resolution XPS mode UPS mode Ultimate	 <520 meV @ 60 kcps (Ag $3d_{5/2}$, Al K_α 47 W, 200 µm spot) <107 meV @ 10 kcps (Ag Fermi Edge, He I, 1 mm spot) <2.5 meV
Working Distance	27.75 mm
Entrance Slits	8
Maximum Bakeout Temperature	180 °C
Mounting Flange	DN 150 CF
Shielding	Double µ-metal
Weight	ca. 100 kg

Power Supply HSA 3500 plus	
Voltage Ranges	100 V, 400 V, 1500 V, 3500 V
DAC Resolution	24 bit
Voltage Setting Accurancy	20 bit
Voltage Ripple and Noise	< 250 µV @ 400 V
Warmup Time	30 min
Weight	Approx. 15 kg
Size	45 cm (W) x 32 cm (H) x 50 cm (D)



Printed in July 2010

SPECS Surface Nano Analysis GmbH
Voltastrasse 5
13355 Berlin
Germany

Tel. +49 30 46 78 24-0
Fax +49 30 46 42 08-3
Email support@specs.com
Web www.specs.com

ISO 9001 Certificate

Your Local Representative: