Tescan TENSOR

Improved and Enhanced Analytical STEM Made as Easy as SEM

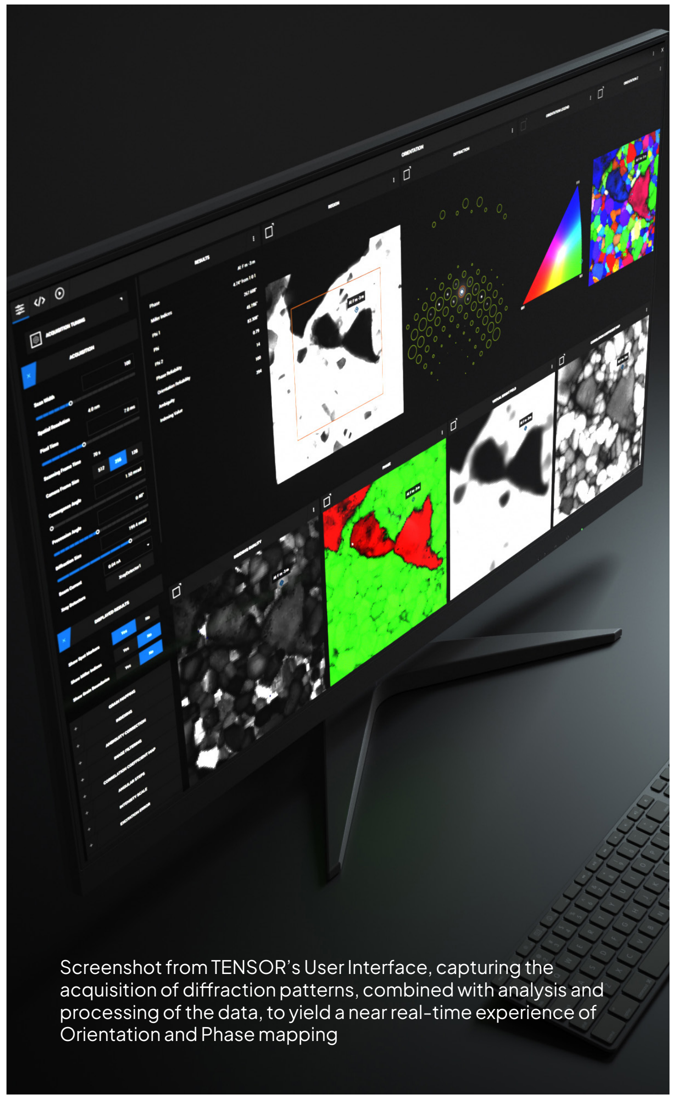
The first multimodal, fully integrated, precession-assisted, analytical STEM and 4D-STEM

Tescan TENSOR is a new multimodal analytical STEM microscope optimized for advanced electron diffraction measurements.

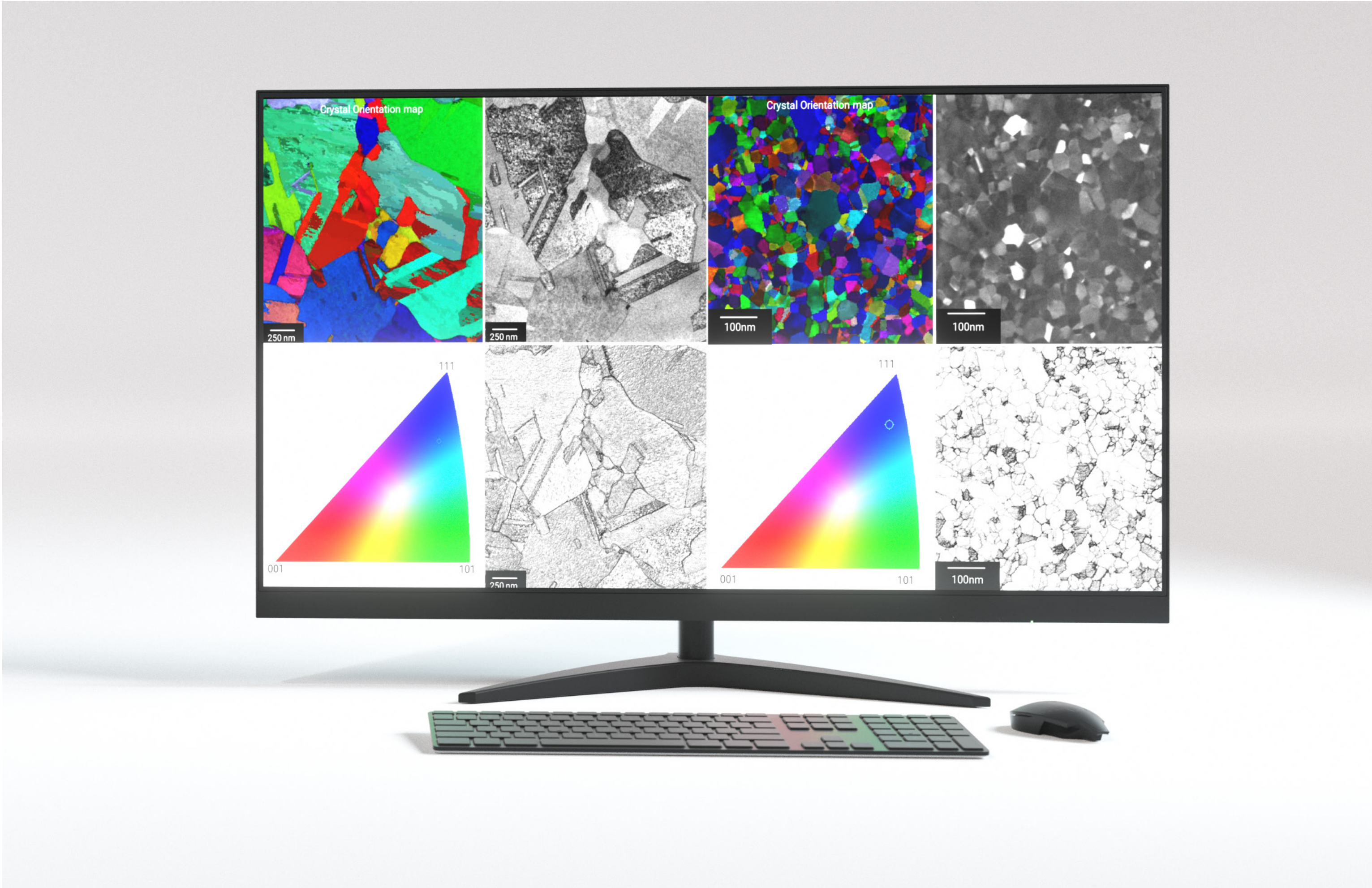
Take advantage of TENSOR's unprecedented usability and stand-out 4D-STEM performance to boost the productivity of morphological, chemical, and structural characterization of metals, alloys, functional materials, thin films, and nanoparticles.

New Multimodal, Precession-Assisted, Analytical STEM Optimized for 4D-STEM Applications, Automated Workflows, and High Productivity

Tescan TENSOR is the world's first analytical STEM microscope optimized for electron diffraction and 4D-STEM characterization of nanoscale morphological, compositional, and structural properties of functional materials, thin films, and nanoparticles at near-UHV conditions. The TENSOR features fully integrated beam precession for enhanced electron diffraction data at unrestricted detector readout speed, enabling on-the-fly data processing and interactive sample analysis. The stand-out 4D-STEM performance combined with a new level of microscope automation and unprecedented usability translates into high throughput and productivity. Both 2D area mapping and 3D volume tomography characterization measurements are available.



Screenshot from TENSOR's User Interface, capturing the acquisition of diffraction patterns, combined with analysis and processing of the data, to yield a near real-time experience of Orientation and Phase mapping



Analytical 4D-STEM: The full picture of electron beam-specimen interaction

The technique of 4D-STEM (i.e. electron diffraction mapping) captures all scattered electrons from each scanned pixel of an analyzed sample. It is therefore the method of choice for true nanoscale characterization of material properties such as morphology, chemistry, and structure. Moreover, Tescan TENSOR acquires both diffraction pattern and EDS spectrum at each pixel – fast and with perfect synchronization. Together, diffraction and spectroscopy data encapsulate the full picture of electron beam-specimen interaction, from which a wide range of material properties can be derived.

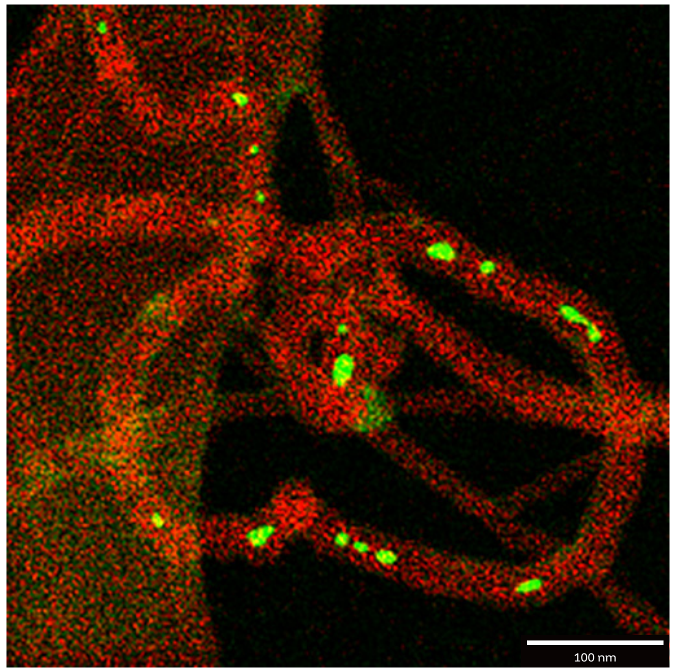
Real-time Analysis and Processing of 4D-STEM data

A truly unique feature of Tescan TENSOR is Explore™, TENSOR's integrated platform for the acquisition and on-the-fly processing and analysis of large-scale scanning electron diffraction datasets. Explore™ brings 4D-STEM measurements to materials scientists, semiconductor researchers, failure analysis engineers, and crystallographers, without requiring expert knowledge of STEM microscope optics or diffraction data post-processing and analysis.

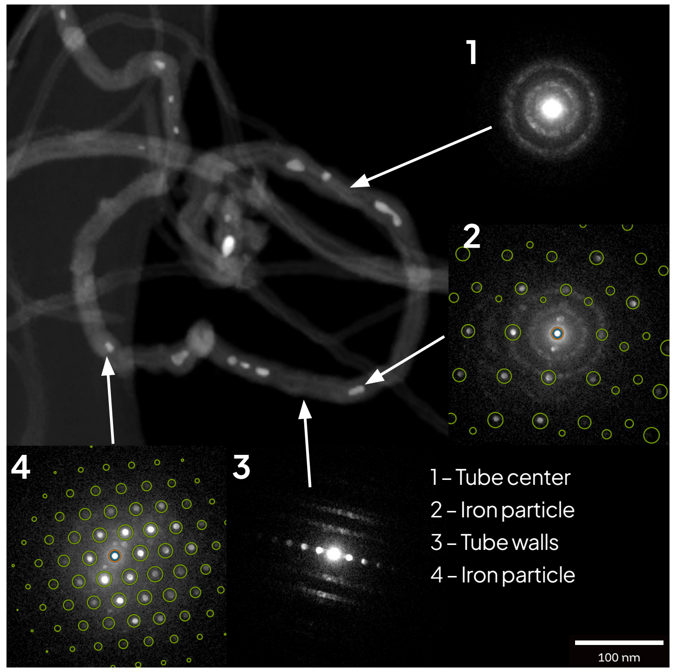
Tescan TENSOR: An analytical STEM that is as easy to use as an SEM

Scientists, engineers, technicians, and students have long wanted a TEM solution that is readily usable without weeks or months of training on complicated electron-optical adjustments and alignments. Tescan TENSOR lets users spend their valuable time on the microscope on the investigation of their samples, instead of aligning the TEM/STEM optics. This is achieved by the implementation of "Measurements" with preset optical properties such as beam current, convergence angle, and probe size intuitively while all alignments are refined automatically without user intervention. This includes turning beam precession ON or OFF—all adjusted and aligned automatically.

The result: A multimodal analytical 4D-STEM microscope that is as easy to use as Tescan SEM and FIB/SEM instruments, with all the efficiency and benefits of results-driven electron microscopy. Ultimately, this approach also yields economic benefits, such as better accessibility for novice or new users, higher throughput and yield of good results, leading to higher tool utilization that ultimately supports a rapid return on investment.



EDS elemental map, with carbon shown in red and iron in green, identifying iron metal particles encapsulated in carbon nanotubes.



Nanobeam Electron Diffraction (NBED) patterns providing information on the crystallinity of carbon nanotube and encapsulated metal particles.

Differentiated 4D-STEM

Performance

Performance of Tescan TENSOR's 4D-STEM capabilities is supported by ultrafast and precise synchronization of scanning with (direct electron) diffraction imaging, EDS acquisition, electron beam precession, beam blanking, and on-the-fly analysis and processing of the acquired data.

This has been made possible by integrating state-of-the-art components and techniques from the ground up:

- Hybrid pixel, direct electron detection (DED) for diffraction
- Ultra-high vacuum (near UHV) within the sample area
- Fast and fully integrated precession electron diffraction (PED)
- Very fast beam blanker for precise analytical STEM data
- Large solid angle, symmetrical, window-less EDS system
- Data acquisition with on-the-fly data processing and 4D-STEM analysis in Explore™

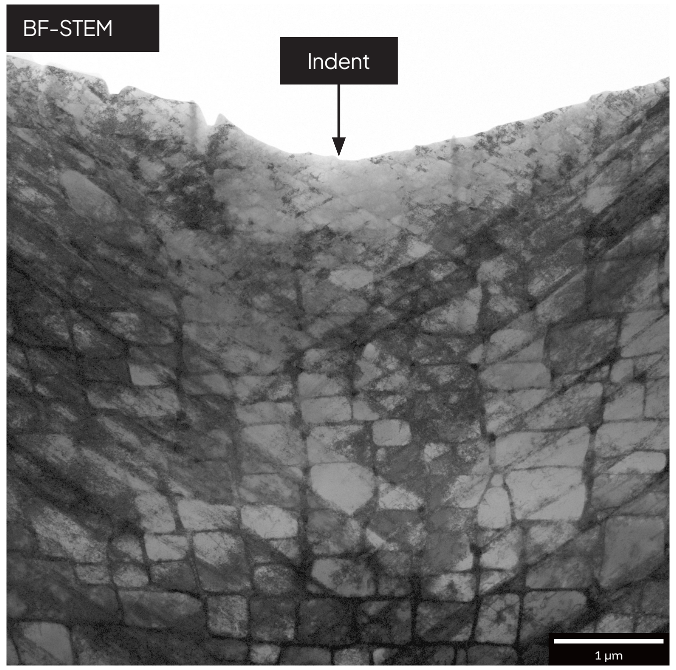
Analytical 4D-STEM Explained

The full picture of the electron beam–specimen interaction

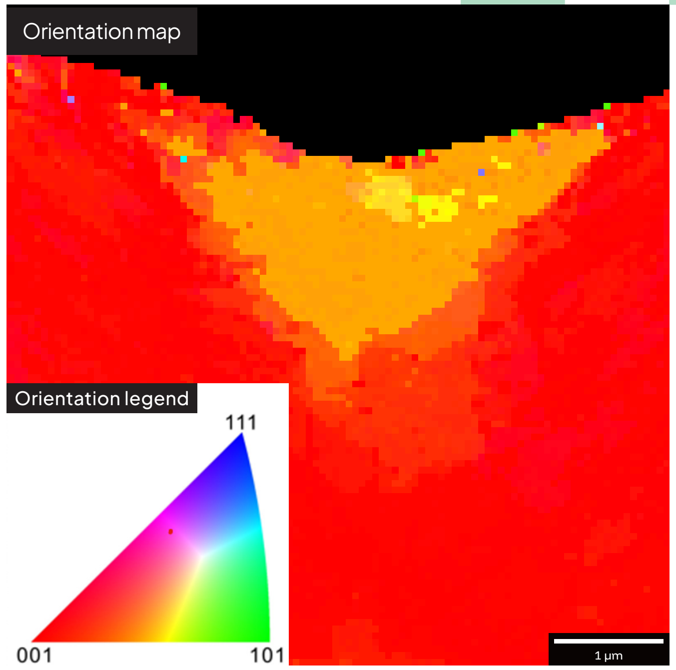
4D-STEM (i.e. electron diffraction mapping) is an evolution of scanning transmission electron microscopy (STEM) that takes full advantage of innovations in the field of hybrid-pixel, direct electron detectors to capture an electron diffraction pattern at each pixel in the STEM image. With this methodology, the microscope acquires a 2D reciprocal space image (electron diffraction pattern) tagged to every pixel as the transmitted electron beam is scanned across a 2D region of interest (ROI) in real space, hence the term 4D-STEM.

Tescan TENSOR takes 4D-STEM one step further, acquiring a precisely synchronized EDS spectrum together with the electron diffraction pattern at each scanned pixel in the 4D-STEM dataset. We refer to this unique capability as Analytical 4D-STEM.

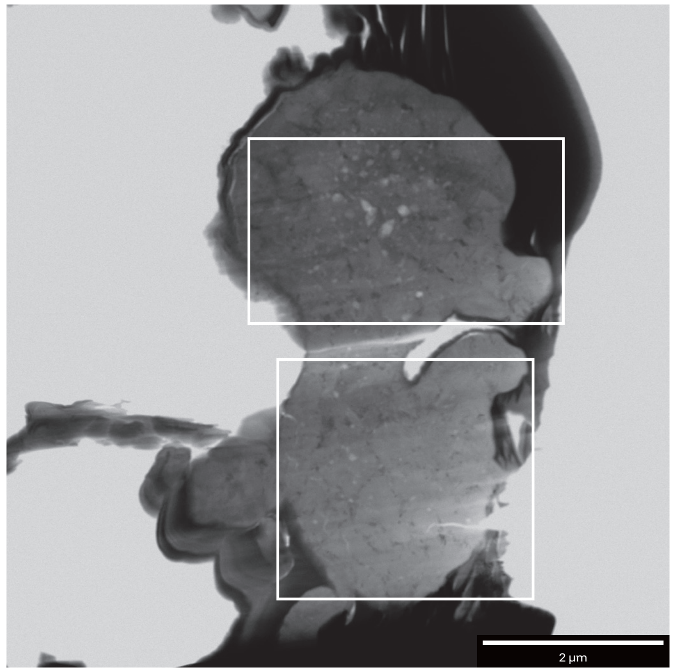
Analytical 4D-STEM can be combined with more conventional STEM and STEM tomography measurements to provide a comprehensive solution for nanoscale, multimodal characterization of functional materials, thin films, and/or synthetic or natural crystals.



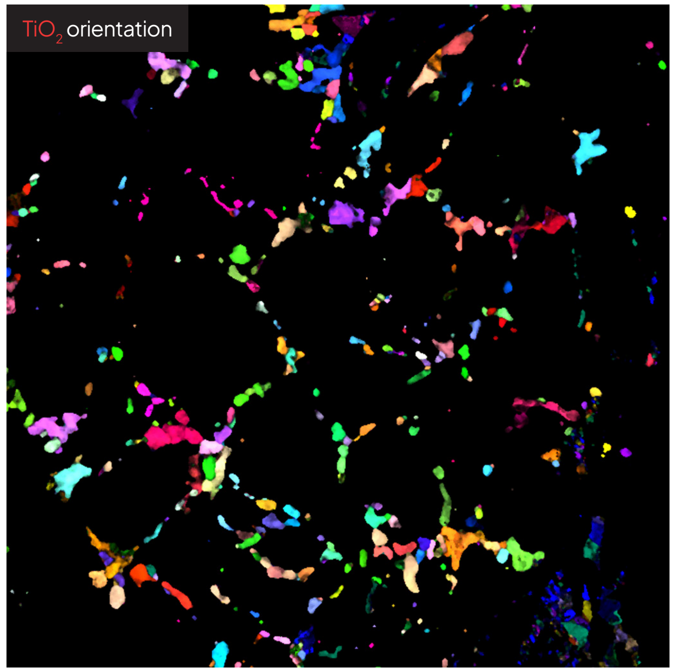
STEM Bright Field image, showing the deformation of a Nickel Alloy single crystal under the impact zone of the indent.



Orientation map of recrystallized and reoriented Nickel Alloy crystals, showing recrystallized grains have reoriented from [001] to [103].



STEM Dark Field image of Titanium Lithium Phosphate anode particles.



Orientation map of Titanium Oxide (TiO_2) particles distributed along the grain boundaries of the phosphate anode particles.

Tescan TENSOR
Integrated Measurements

Optics developed for Measurements, not Measurements for Optics

Tescan TENSOR provides a range of optimized, multimodal, “out-of-the-box” STEM, EDX, 4D-STEM as well as 3D-ED and STEM/EDX tomography measurements. Applying these to your sample is as easy as pushing a button and does not require extensive experience with TEM/STEM optics adjustments and alignments, scanning electron diffraction data acquisition, or 4D-STEM data analysis and processing.

STEM Imaging (Bright Field, Annular Dark Field and High-Angle Annular Dark Field)

Used primarily for sample navigation and feature size measurement, STEM images up to 1 gigapixel can be acquired quickly (up to 10 Mpixels/sec), with integrated scintillator-based bright field and annular dark field/high-angle annular dark field detectors.

STEM Lattice Imaging

STEM lattice imaging measurement with automatically assisted alignment can be used to acquire atomic-resolution (down to 2.8 Å) bright field and high-angle annular dark field STEM images.

EDX Composition Analysis

Acquires elemental maps at high EDS count rates (>> 100 kcps), thanks to two symmetrically arranged, windowless EDS detectors, with the total solid collection angle of 2.0 steradian. Both qualitative EDX mapping and quantitative EDS compositional analysis are fully integrated in the Explore™ software as well.

Phase and Orientation Mapping

Select the phase-orientation measurement for interactive phase analysis and grain orientation mapping of single- and multi-phase polycrystalline and amorphous materials. A small electron beam (down to < 1 nm) is scanned across the specimen while diffraction patterns are acquired at thousands of frames per second and automatically indexed on the fly. Electron beam precession can be enabled with the push of a button to dramatically improve the quality and accuracy of the results.

Strain Mapping

Strain measurement combines nanobeam electron diffraction with electron beam precession to allow accurate and high-precision strain mapping in single crystals. Once a grain is tilted to a zone axis with the automation-assisted specimen tilting, a small (1–2 nm) precessed electron beam scans across the crystal and acquires thousands of diffraction patterns. Precession improves the quality of the diffraction patterns for strain analysis by exposing more diffraction spots and producing more uniform spots. Strain maps are analyzed on-the-fly to yield 2D strain information to the operator just in few minutes.

Virtual STEM

Virtual STEM is a highly configurable 4D-STEM measurement that allows real-time reconstruction and visualization of STEM images from 4D-STEM datasets. Virtual spot or annular apertures can be defined by the user directly on acquired diffraction patterns, and images are reconstructed using those apertures. Alternatively, the analytical 4D-STEM dataset can be exported to open source, pixelated STEM data analysis and processing platforms, such as HyperSpy, LiberTEM or py4Dstem.

STEM and EDS Tomography

STEM and STEM-EDS tomography are two measurements for the acquisition and reconstruction of 3D morphology (STEM) or elemental distribution (EDS) volumes of the sample, for subsequent analysis and visualization in a range of 3D imaging software, including the Tescan 3D Volume Analysis software package.

Diffraction Tomography

TENSOR can also be used for 3D-ED (micro-ED) diffraction tomography data acquisition and analysis. A nearly parallel beam (<0.05 mrad), with beam precession, can be formed into a spot as small as 40 nm, and up to 2 µm in diameter. Diffraction patterns are then acquired while the specimen is tilted (stepwise) through a large range of angles. This provides a superior solution for the structural analysis of synthetic or natural sub-micron crystals and nanoparticles. The optionally available *ePETS* software can be used to (automatically) analyze the acquired 3D Precession Electron Diffraction (3D PED) dataset to yield the unit cell dimensions and further proceed to 3D structure determination in *JANA* or other 3rd party software packages.

Differentiated Performance of Tescan TENSOR

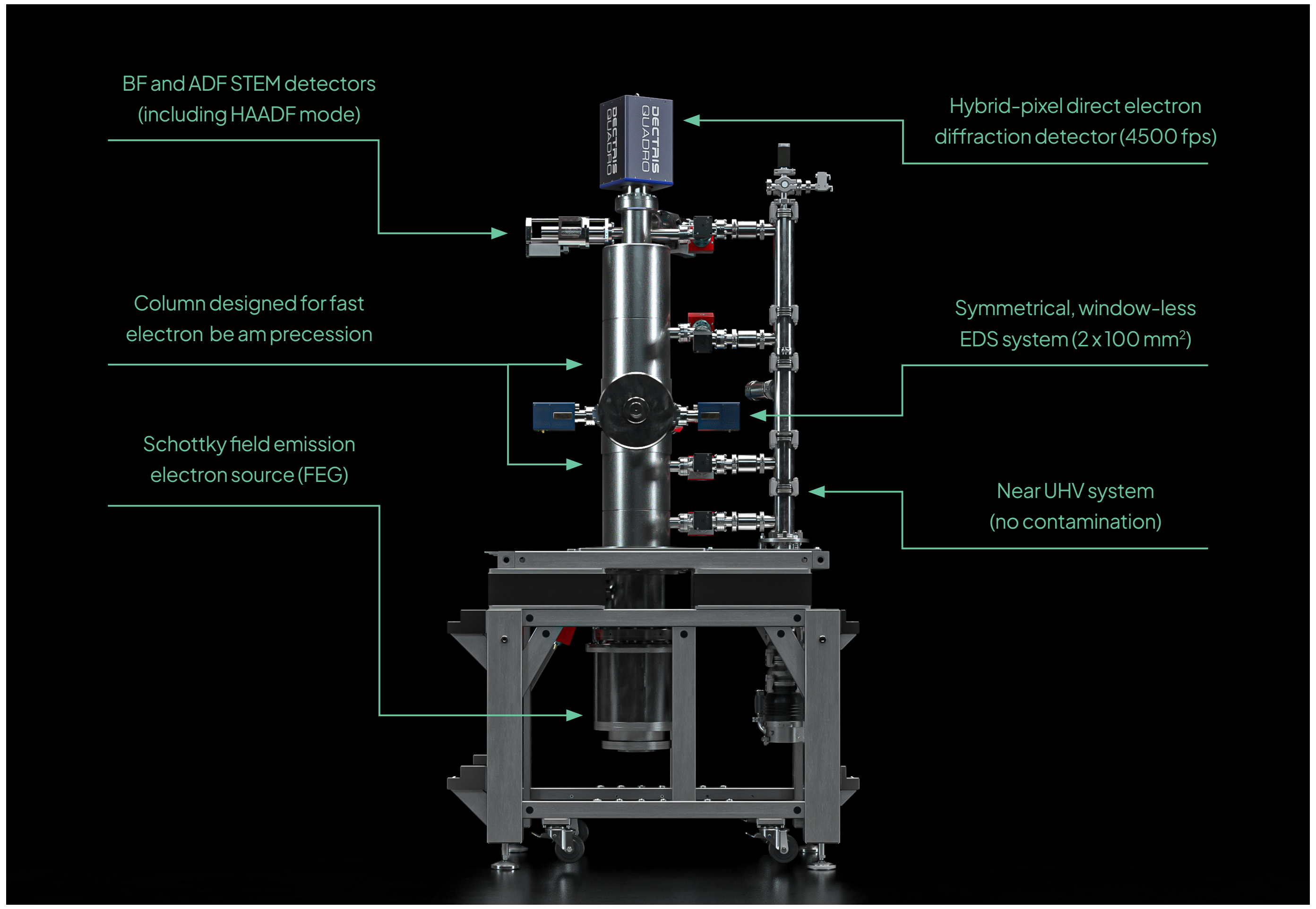
Integration designed from the ground up

Performance, usability, and even availability of 4D-STEM measurements has historically been compromised by the lack of integration of 4D-STEM components on TEM/STEM columns that were not originally designed for this purpose. Not so with Tescan TENSOR which has inherently implemented synchronization of:

- Electron beam scanning
- Electron beam blanking
- Electron beam precession
- Electron diffraction mapping (4D-STEM)
- EDS signals acquisition
- BF/ADF STEM imaging

Coupled with robust software solutions means that Tescan TENSOR is a purpose-built microscope that was designed, from the ground up, for multimodal analytical STEM applications.

KEY MODULES of Tescan TENSOR



Rendering of the system's column and integrated components, showing the direct electron detector, electron beam precession, and EDS, on an inverted column (Schottky electron source at the bottom, and the detector at the top).

DECTRIS QUADRO Inside

The integrated hybrid-pixel direct electron detector for diffraction is ideally suited for precession-assisted 4D-STEM

An integral component of Tescan TENSOR is the QUADRO direct electron detector from DECTRIS, a leading developer and manufacturer of accurate, high-performance, hybrid-pixel X-ray and electron detectors. The properties of the DECTRIS QUADRO, notably its large detector size (512×512 pixels), sensitivity, and speed (4,500 fps @ 8 bit) make this detector ideal for precession-assisted 4D-STEM applications.

Precession Electron Diffraction

Extract more information from electron diffraction patterns

Integrated electron beam precession is a key feature of Tescan TENSOR. The ability to precess the electron beam means that the incident electron beam is tilted and continuously rotated around the central axis of the microscope. Electron beam precession must be aligned carefully to ensure that the precession pivot point coincidences with the surface of the specimen, and that the electron beam converges in the smallest possible round spot of the microscope, at the pivot point on the scanned sample. This alignment is achieved effortlessly and automatically, thanks to a unique electron column design and software automation that are both integrated into the fundamental design of the new system architecture of Tescan TENSOR.

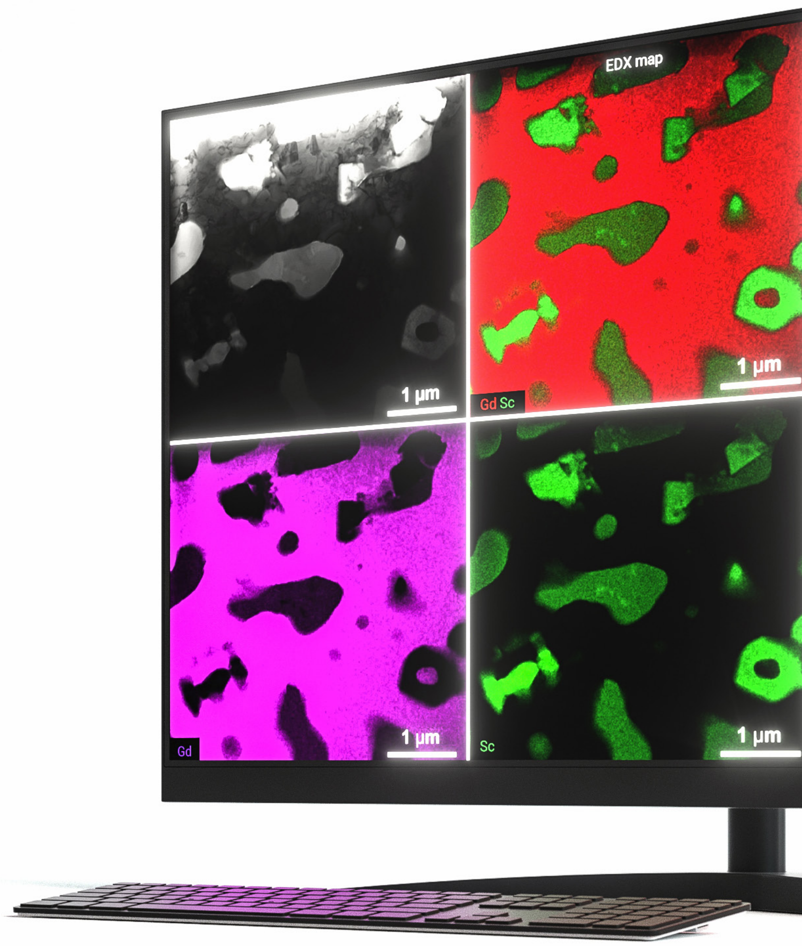
Tescan TENSOR provides easy and intuitive operation, both with and without electron beam precession, throughout the full range of STEM, EDS, and 4D-STEM measurements, notably for orientation and phase mapping, as well as strain mapping, but also for virtual STEM and diffraction tomography (3D ED).

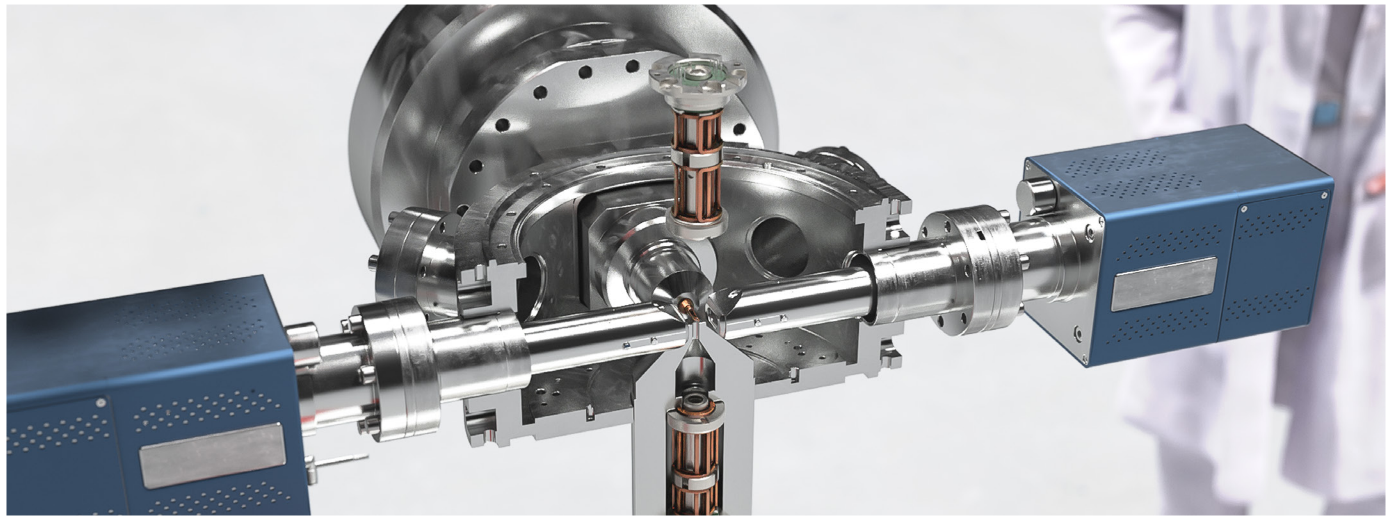
Precession causes the Ewald sphere to rock through reciprocal space, which brings many positives and advantages:

- The effects of dynamical electron interactions are minimized while the geometry of the diffraction pattern is maintained;
- Many more reflections in both zero- and higher-order Laue zones are visible compared to those of a static Ewald sphere (without beam precession);
- Intensities are integrated through the Bragg condition within the precession angle and therefore are not dominated by complex contrast patterns.

Without dynamical diffraction artifacts, the resulting precession electron diffraction patterns are well suited for a variety of applications. Benefits include better differentiation of diffraction patterns when doing orientation and phase mapping, or improved precision in strain mapping. Tescan TENSOR uses NanoMEGAS' proven and trusted ASTAR® software algorithms for template creation and diffraction pattern indexing.

Higher order reflections also improve ab initio structure determination of nanocrystalline materials. For structural determination using precession-assisted electron diffraction tomography (3D ED with precession, i.e. 3D PED), Tescan TENSOR offers the optionally available *ePETS* software, a version of the academic PETS software from Dr. Lukas Palatinus (pets.fzu.cz) that has been customized for Tescan.





Rendering of the sample area, showing the two symmetrically arranged, window-less EDS detectors, with XY and precession scan coils in the compound objective lens.

Integrated Energy Dispersive Spectroscopy (EDS)

High count rates from two symmetrically arranged, window-less EDS detectors

Tescan TENSOR is equipped with two symmetrically arranged, window-less EDS detectors, cumulating in the total 2.0 steradian data collection solid angle to allow high count rates for measurements such as composition (elemental mapping) or EDS tomography. Fully integrated and synchronized EDS system is essential for correlative 4D-STEM / EDS analytical measurements, such as phase mapping of complex materials containing phases with very close lattice parameters.

Near Ultra-High Vacuum

Eliminates contamination from hydrocarbons in the column vacuum

The design of the Tescan TENSOR column incorporates modular UHV components, such as ConFlat (CF) Flanges and copper gaskets, to achieve a vacuum of 10^{-6} Pa in the sample area. This practically eliminates contamination of your specimen from hydrocarbons present in the column.

Usability

A novel approach to 4D-STEM User Experience

At the time of design of Tescan TENSOR, we identified a need for much better integration between the microscope, its detectors, the specimen, the user, and even the data analysis and interpretation, compared to systems with multiple components accreted onto legacy TEM platforms (i.e. conventional TEM/STEM microscopes). We developed a concept of a “specimen/results-centric” system, as opposed to a more traditional “instrument-centric” system. If the focus is supposed to be on the specimen and the results, and not on the instrument, then the instrument operation must be transparent to the user. The result is a scanning transmission electron microscope that is designed for measurements, as opposed to a solution where measurements must be designed for the microscope.

There is no set of applications that benefits more from application-driven design than 4D-STEM and the resurgence in the use of electron diffraction. The electron diffraction scanning (4D-STEM) technique is unique as it captures the full information from electron scattering in a sample and there are endless possibilities how to extract the information from an acquired dataset using different data processing and analyses. For example, you can map strain and electric field strength with extreme precision. You can map material's phases and grains orientation. Tescan TENSOR makes these analyses transparent to users who are not electron microscopy experts. Select any of these measurements, and the tool automation will take care of the rest, while processing the extracted information in near real-time. Users can therefore focus on the analysis of their samples without being held up by complicated setup tasks and achieve optimized results in the shortest amount of time.

Although a technology-driven design is less challenging for scientists doing fundamental research, the growing need for nanoscale characterization in the field of Materials Science, both in Academia and Industry, asks for „usable tools“ as opposed to „development instruments“. This is particularly important for ensuring that utilization and productivity supports high yield of accurate results and the return on investment from increasingly complicated and expensive scientific instruments.

Tescan FIB/SEM (Automated) TEM Lamella Preparation Solutions

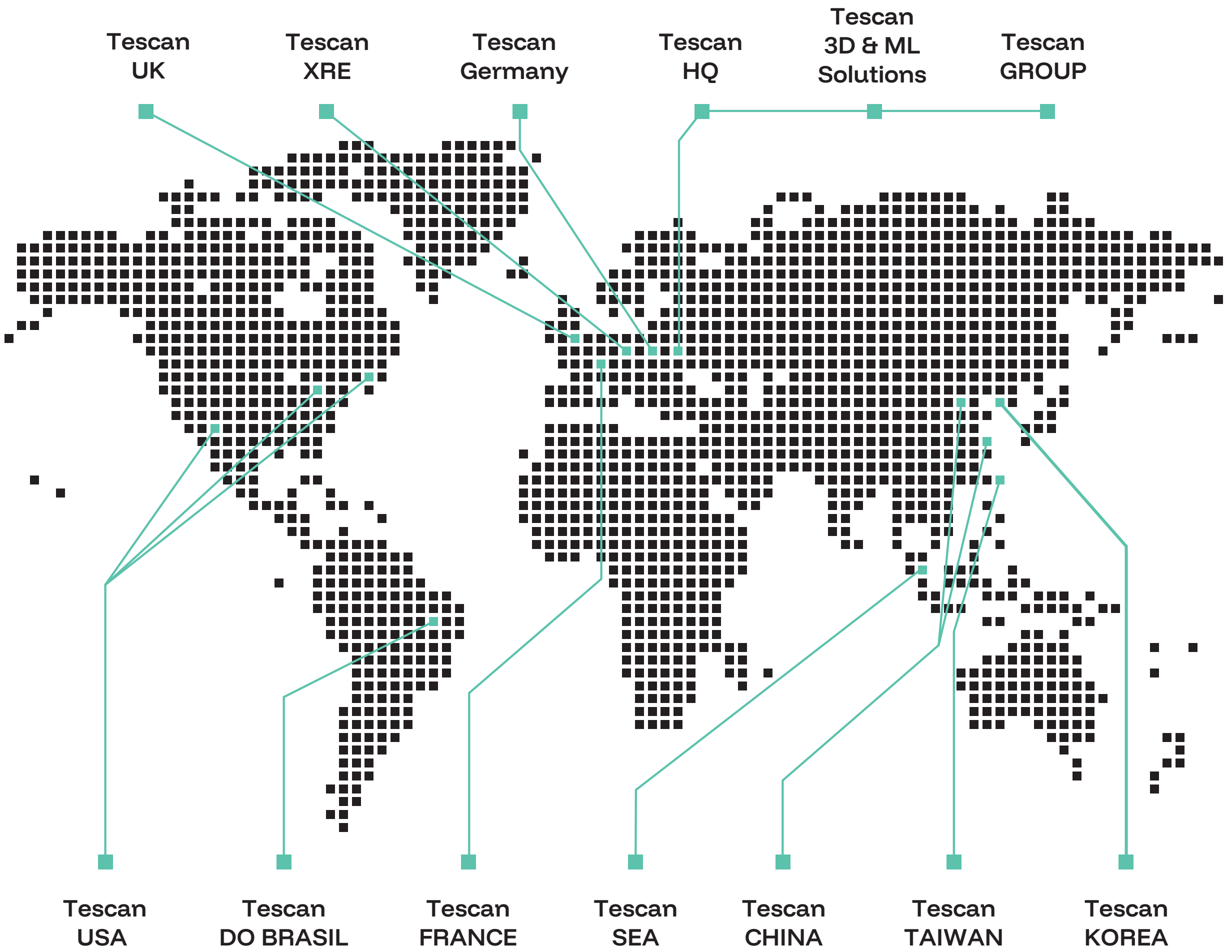
Application recommendation:

Volume characterization

			Technology	Applications
 **Tescan AMBER X**	FIB-SEM for multi-scale, multi-modal characterization with Xe Plasma FIB for large area sample processing and Ga-free sample preparation.	MS Materials Science LS Life Sciences ES Earth Science	i-FIB+™ Xe plasma FIB column Field-free UHR SEM In-Column detectors Rocking stage	Large Scale analysis FIB-SEM tomography Micro analytical characterization (EDS/EBSD and ToF-SIMS) Ga free TEM prep
 **Tescan SOLARIS X**	Designed to SEM and STEM imaging, Failure analysis for advanced packaging, Ga-free sample preparation.	SC Semiconductors LS Life Sciences	i-FIB+™ Xe plasma FIB column Immersion UHR-SEM Selective signal collection Rocking stage	Ga free TEM prep FIB-SEM tomography Cross-sectioning IC planar delayering
 **Tescan AMBER**	Easy to use and versatile FIB-SEM for nanoscale materials characterization and sample preparation on a variety of materials.	MS Materials Science LS Life Sciences ES Earth Science	Orage™ Ga FIB column Field-free UHR SEM In-Column detectors Advanced TEM prep geometry	TEM prep FIB-SEM tomography Micro analytical characterization (EDS/EBSD and ToF-SIMS) Nanofabrication
 **Tescan SOLARIS**	For high resolution SEM imaging, the highest-precision Ga FIB thin lamella preparation, and nano prototyping applications.	MS Materials Science SC Semiconductors LS Life Sciences	Orage™ Ga FIB column Immersion UHR-SEM Selective signal collection Advanced TEM prep geometry	TEM prep FIB-SEM tomography E-beam litography Nanoprototyping

Nano characterization

 **Tescan NanoSpace**	Ultra-High Vacuum FIB-SEM platform for operations requiring a specific level of vacuum, such as modification, analyses or nanoprototyping performed on highly surface-sensitive samples.	MS Materials Science SC Semiconductors	Three Beam System Wien Filter – multi ion species Field emission gun Ultra-High Vacuum	Nanoanalyses TOF-SIMS Ion implantation Sensitive surface analyses



Tescan Family
Around the World

Tescan enables nanoscale investigation and analysis within the geosciences, materials science, life sciences and semiconductor industries. The company has a 30-year history of developing innovative electron microscopy, micro-computed tomography, and related software solutions for customers in research and industry worldwide. As a result, Tescan has earned a leading position in micro- and nanotechnology.

For more information visit: www.tescan.com

Tescan

TESCAN GROUP, a.s.
Libušina tř. 21, 623 00 Brno - Kohoutovice / Czech Republic
(phone) +420 530 353 411 / (email) sales@tescan.com / marketing@tescan.com