TESCAN TENSOR

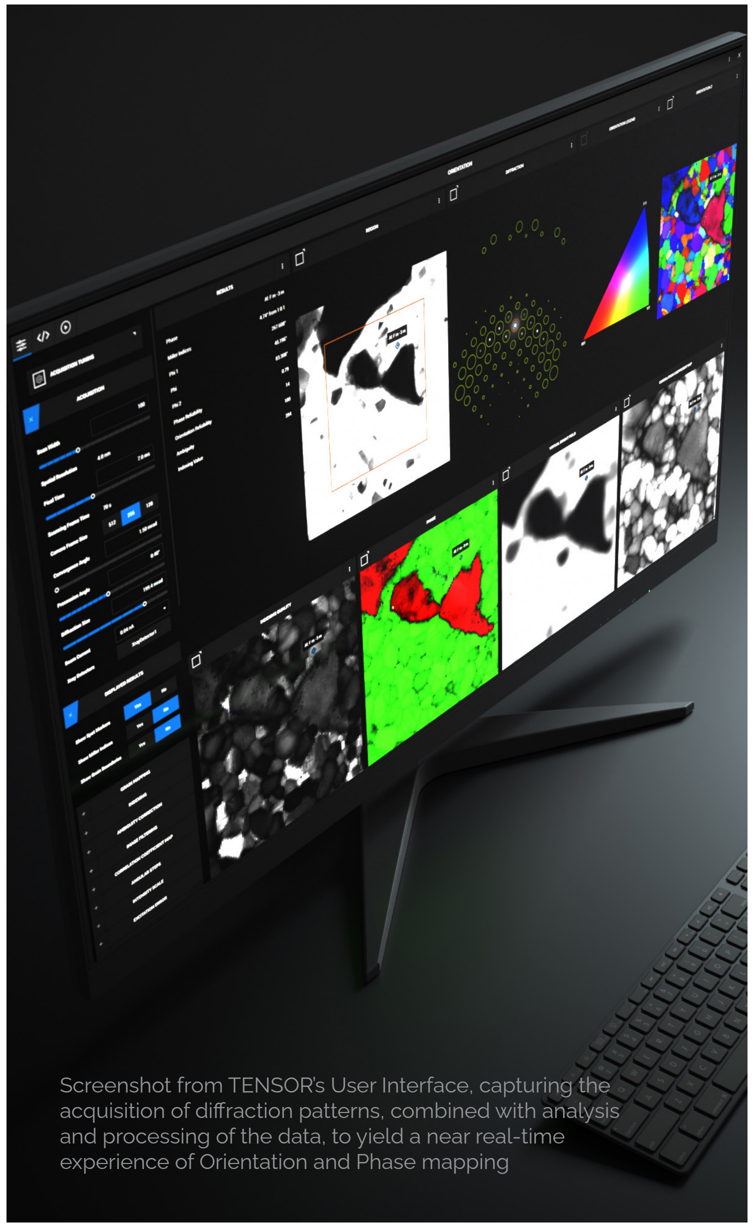
STEM done right

The first near-UHV 4D-STEM that is Integrated, Precession-Assisted, and Analytical.

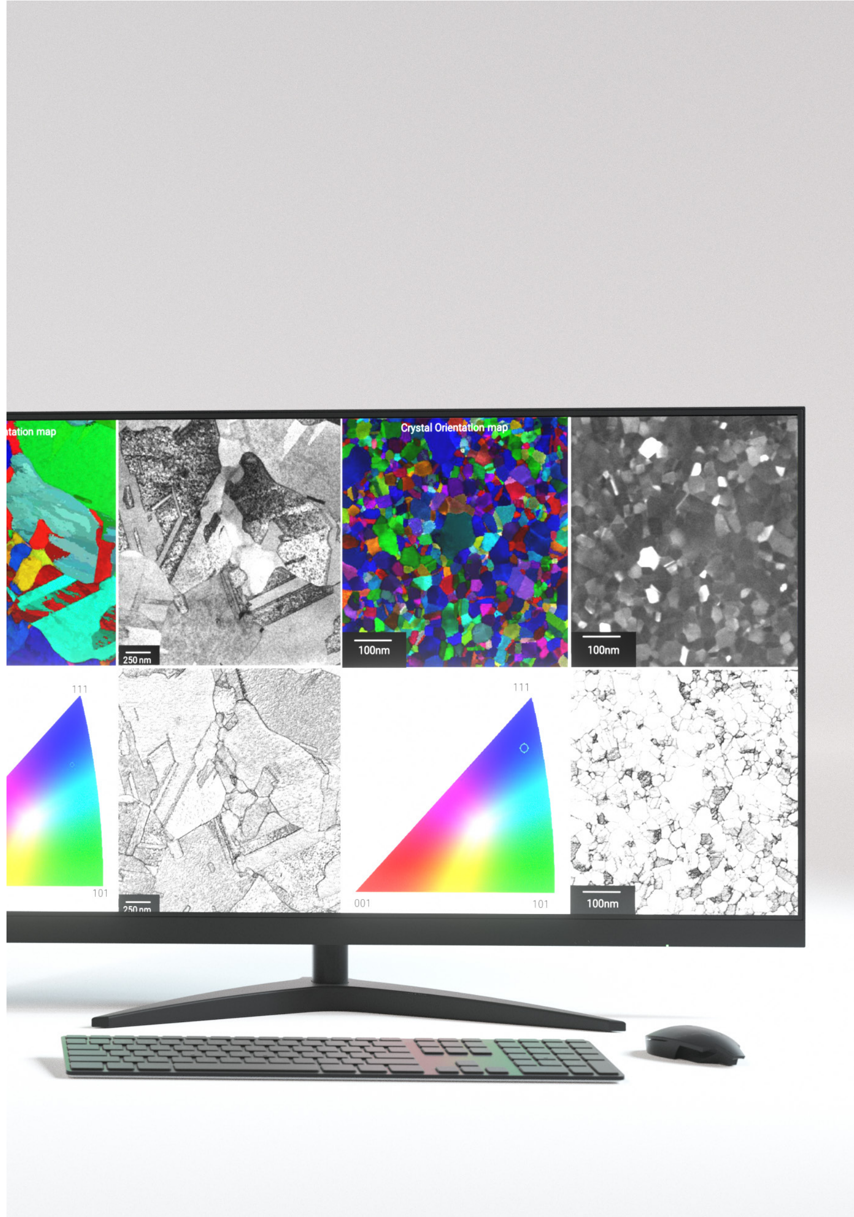
TESCAN TENSOR is the world's first dedicated 4D-STEM for multimodal characterization of nanoscale morphological, chemical, and structural properties of functional materials, thin films, and natural and synthetic particles — with stand-out 4D-STEM performance and unprecedented usability.

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

4D-STEM is the microscopy method of choice for true nanoscale, multimodal characterization of material properties such as morphology, chemistry, and structure. At each pixel in the STEM dataset, TESCAN TENSOR acquires a diffraction pattern and an EDS spectrum, fast, 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.



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



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

A truly unique feature of TESCAN TENSOR is Explore, TENSOR's integrated platform for (near) real-time processing and analysis of large-scale scanning electron diffraction datasets. Explore brings 4D-STEM measurements to materials scientists, semiconductor researchers and failure analysis engineers, and crystallographers, without requiring expert knowledge of STEM optics or 4D-STEM data analysis and post-processing.

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 real-time 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
- ✔ Near-Ultra High Vacuum (UHV) within the sample area
- ✔ Precession Electron Diffraction (PED)
- ✔ Fast, integrated beam blanking
- ✔ Large solid angle, symmetrical, window-less EDS
- ✔ Near real-time 4D-STEM analysis and processing (Explore)

TESCAN TENSOR: A STEM that is as easy to use as a 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 you spend your time on the microscope interacting with your sample, instead of the optics. This is achieved by the implementation of "measurements" with preset optical properties such as beam current, convergence angle, spot size and precession ON or OFF—adjusted and aligned automatically.

The result: an analytical 4D-STEM that is as easy to use as TESCAN SEMs, with all the efficiency and benefits of a results-driven electron microscope. This approach also potentially yields economic benefits, such as better accessibility for novice or new users, leading to higher tool utilization that ultimately supports a rapid return on your investment.

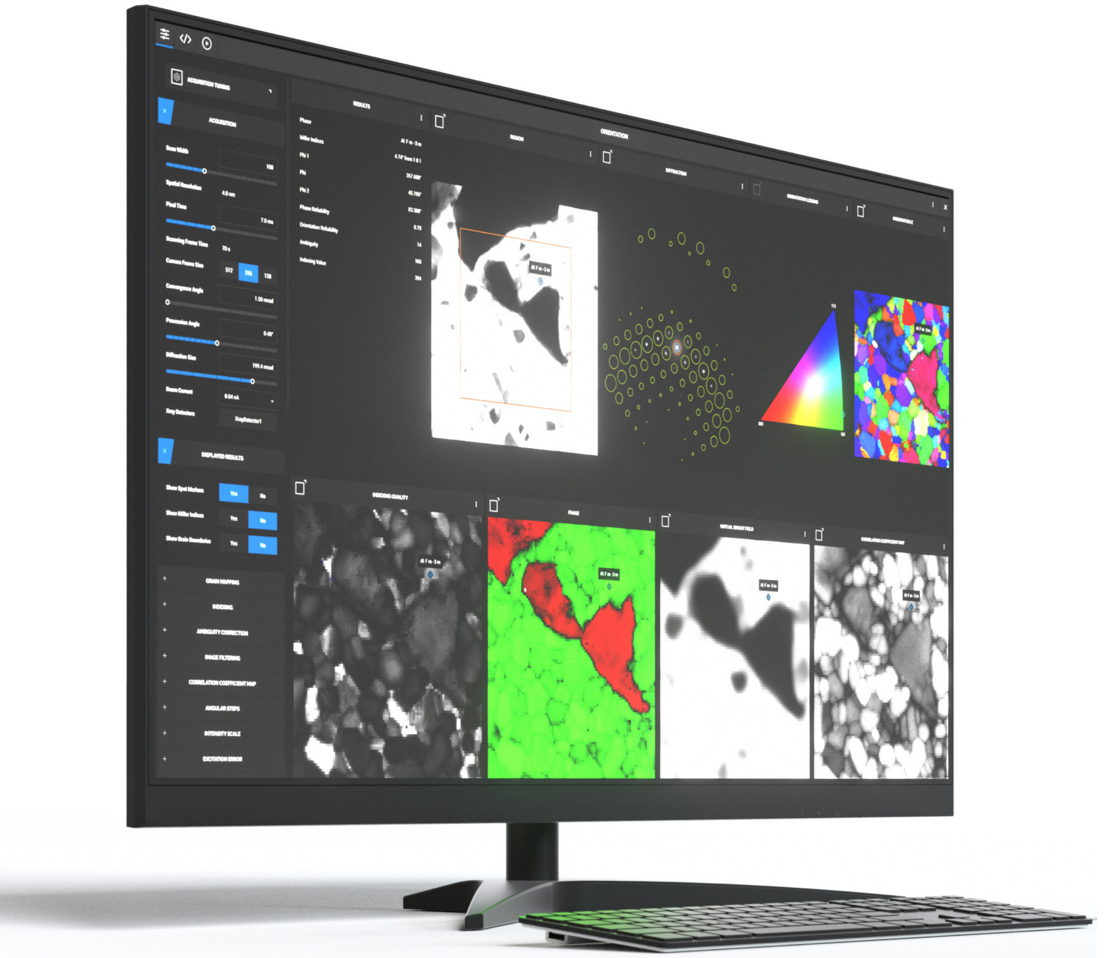
Analytical 4D-STEM Explained

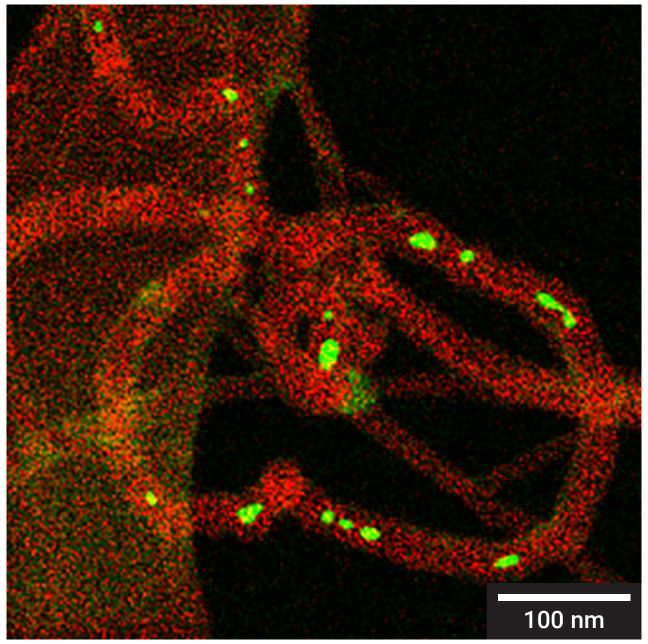
The full picture of the electron beam–specimen interaction

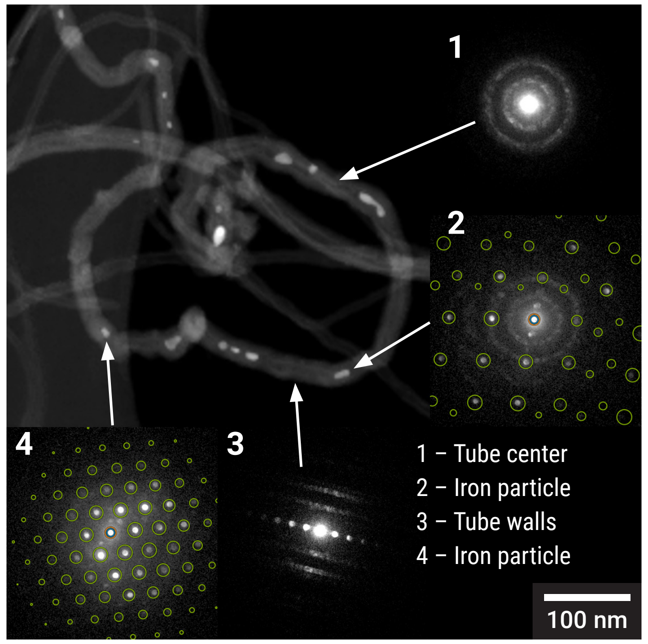
4D-STEM (4D Scanning Transmission Electron Microscopy) is an evolution of Scanning Transmission Electron Microscopy (STEM) that takes full advantage of innovations in the field of hybrid-pixel, direct electron detectors to capture an electron diffraction pattern at each pixel in the STEM image. With 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.

But TESCAN TENSOR takes 4D-STEM one step further, acquiring an EDS spectrum together with the electron diffraction pattern for each 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 synthetic or natural crystals.

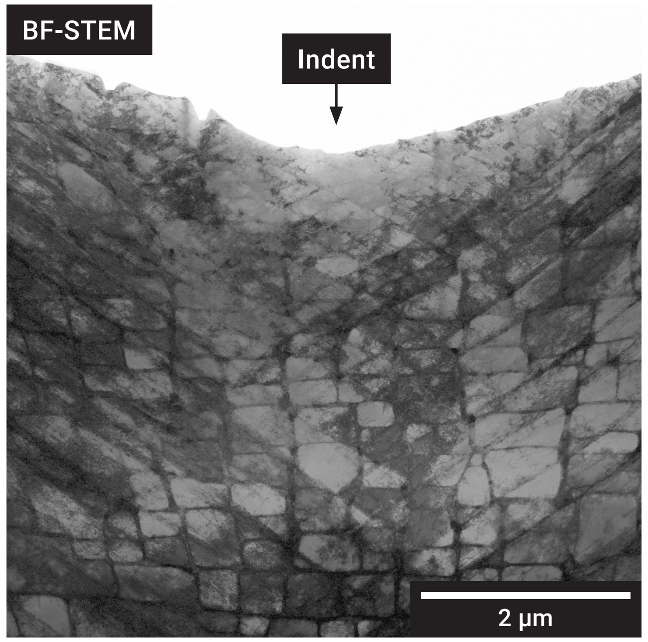


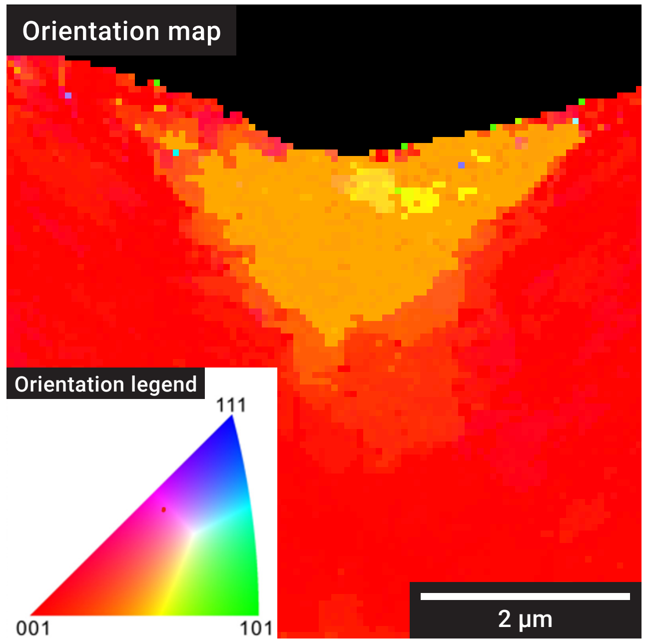




Left: EDS elemental map, with carbon shown in red and iron in green, identifying iron metal particles encapsulated in carbon nanotubes.

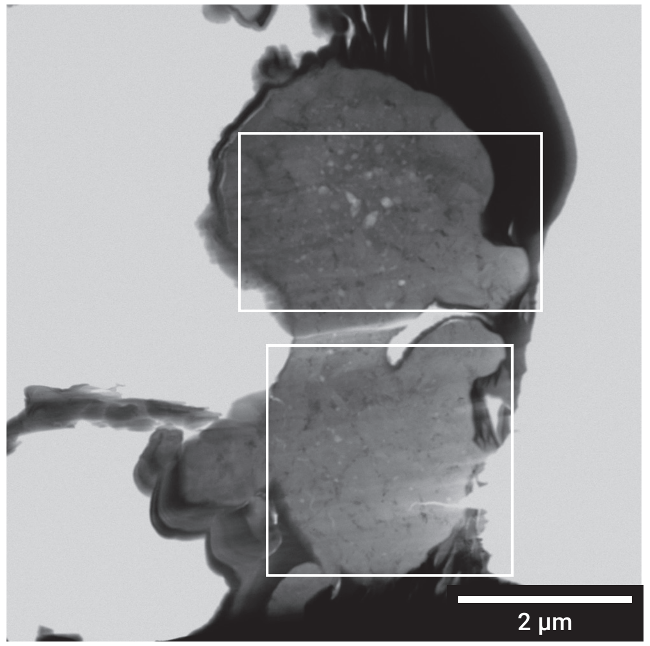
Right: Nanobeam Electron Diffraction (NBED) patterns providing information on the crystallinity of carbon nanotube and encapsulated metal particles.

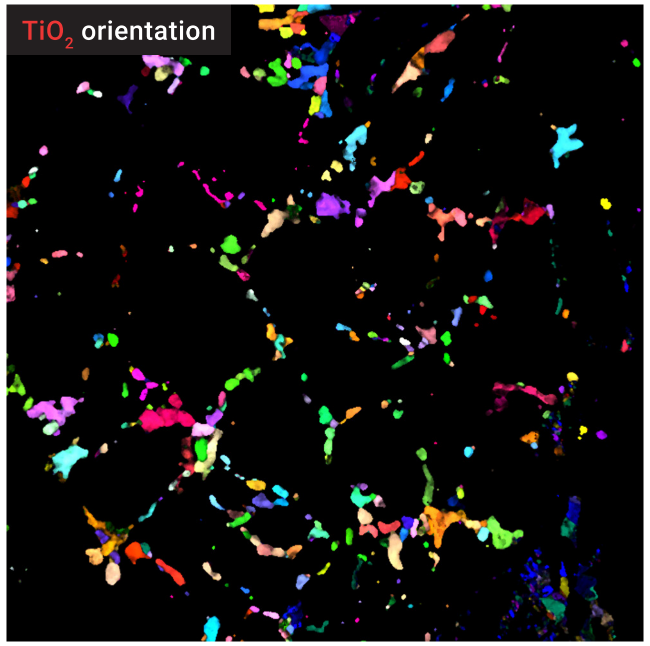




Left: STEM Bright Field image, showing the deformation of a Nickel Alloy single crystal under the impact zone of the indent.

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





Left: ADF image of Titanium Lithium Phosphate anode particles.

Right: Phase and 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, 4D-STEM, and tomography measurements. Applying these to your sample is as easy as pushing a button and does not require extensive experience with (S)TEM 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 bright field (down to 2.8Å) and high-angle annular dark field (down to 3.5Å) STEM images.

Composition

Acquires elemental maps at high EDS count rates (>> 100 kcps), thanks to two symmetrically arranged, windowless EDS detectors, with a cumulative 2 steradian solid collection angle. Qualitative and quantitative EDS analysis is fully integrated in the user experience.

Orientation and Phase Mapping

Select the orientation/phase measurement for near real-time orientation and phase 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 of the results.

Strain Mapping

Strain measurement combines nanobeam electron diffraction with electron beam precession to allow high-precision strain mapping in single crystals. Once a grain is tilted to a zone axis with the automation-assisted specimen tilting, a small (down to 1 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 near real-time strain information to the operator.

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 are two measurements for the acquisition and reconstruction of 3D morphology (STEM) or elemental distribution (EDS) datasets, for subsequent analysis and visualization in a range of 3D imaging software, including TESCAN’s 3D Volume Analysis software.

Diffraction Tomography

TESCAN TENSOR also can be used for 3DED (micro-ED) diffraction tomography acquisition and analysis. A nearly parallel nanobeam, with or without precession, can be focused into a spot as small as 20 nm, and diffraction patterns are 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 and nanoscale particles. The optional PETS Advanced software can be used to analyze the 3D Precession Electron Diffraction (3DPED) dataset to yield the unit cell dimensions.

Differentiated Performance of TESCAN TENSOR

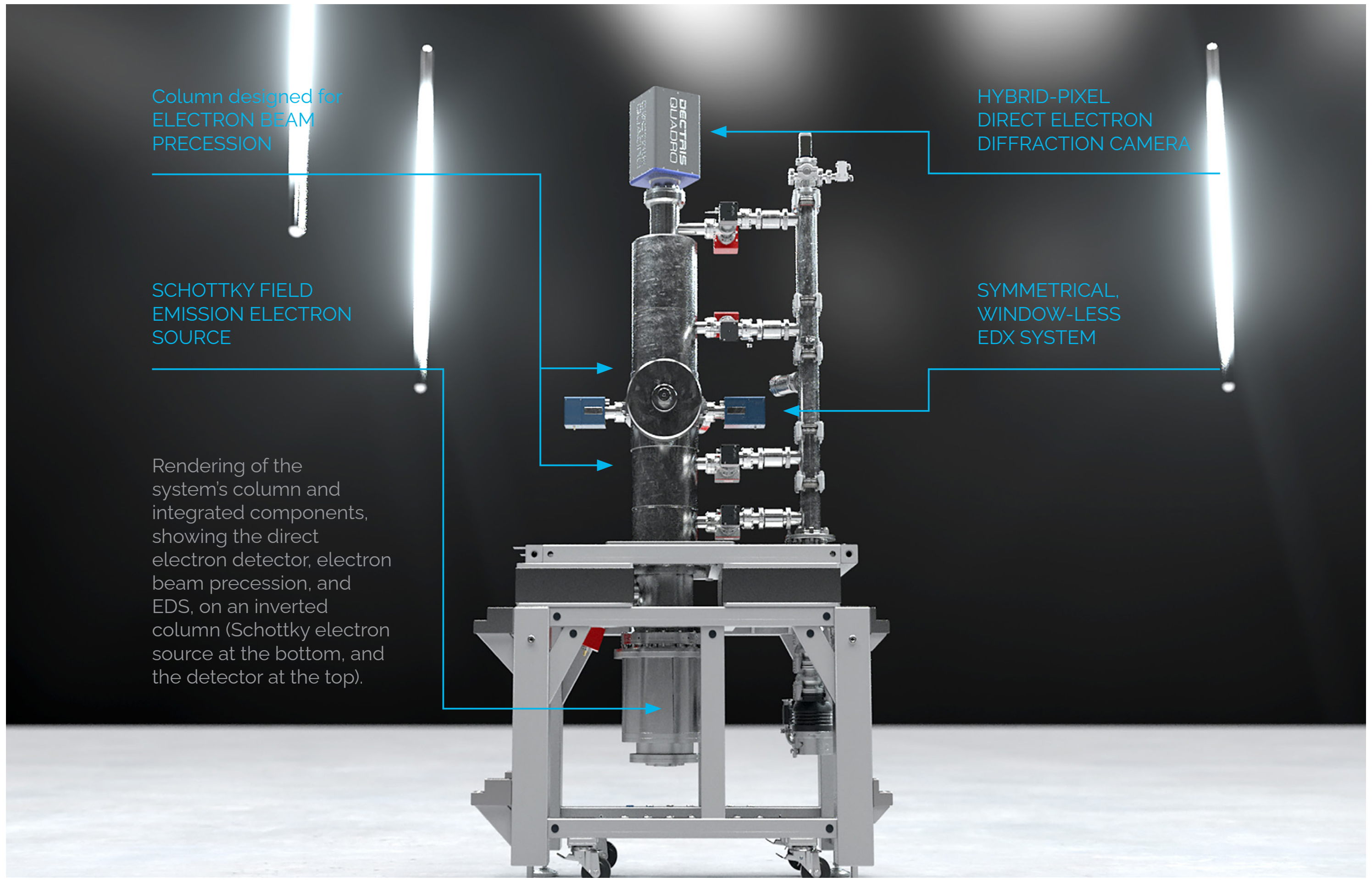
The technology behind TESCAN TENSOR

Integration designed from the ground up

Performance, usability, and even availability of 4D-STEM measurements historically has been compromised by the lack of integration of 4D-STEM components on (S)TEM columns that were not originally designed for this purpose. Not so with TESCAN TENSOR. Synchronization of electron beam scanning with:

- ✔ diffraction imaging
- ✔ EDS acquisition
- ✔ electron beam precession
- ✔ fast beam blanking, and
- ✔ near real-time 4D-STEM data analysis and processing

coupled with robust software solutions, means that TESCAN TENSOR is a purpose-built microscope that was designed, from the ground up, for Analytical 4D-STEM applications.



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 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 (512x512 pixels), sensitivity, and speed (2,250 fps @ 16 bit) make this detector ideal for precession-assisted 4D-STEM applications.

Precession Electron Diffraction

Extract more information from your 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 is coincident with the surface of the specimen, and that the electron beam converges in the smallest possible round spot. 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.

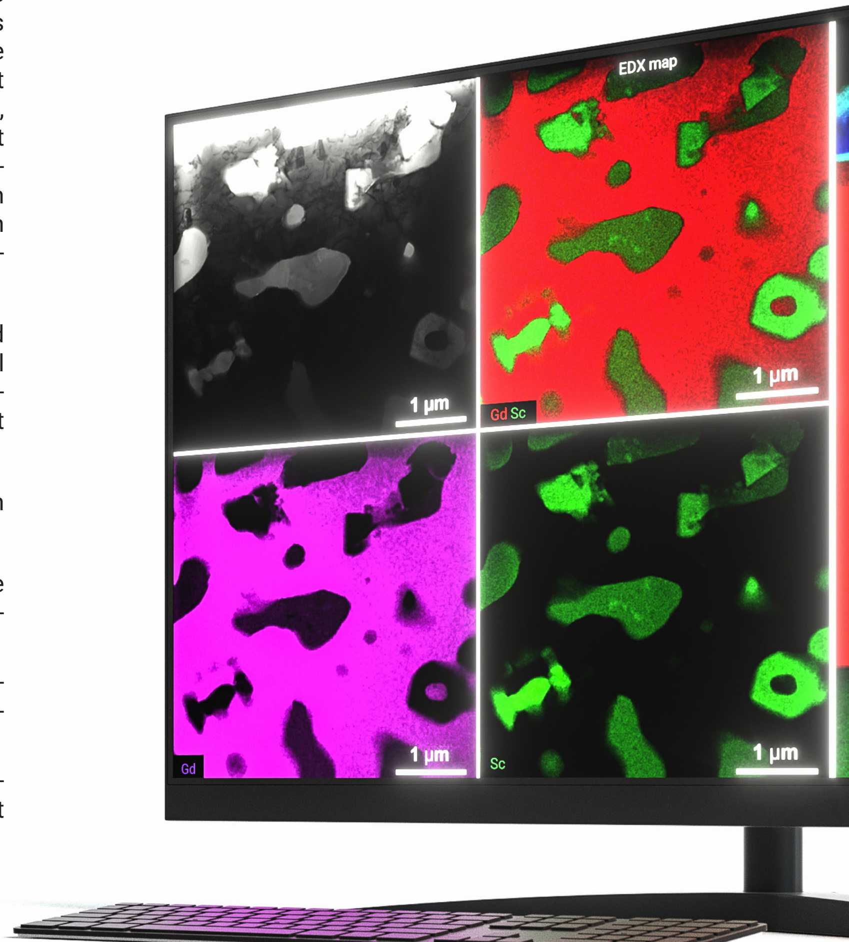
TESCAN TENSOR allows you to easily operate with and without electron beam precession throughout the full range of 4D-STEM measurements, notably for orientation and phase mapping, as well as strain mapping, but also for Virtual STEM and diffraction tomography.

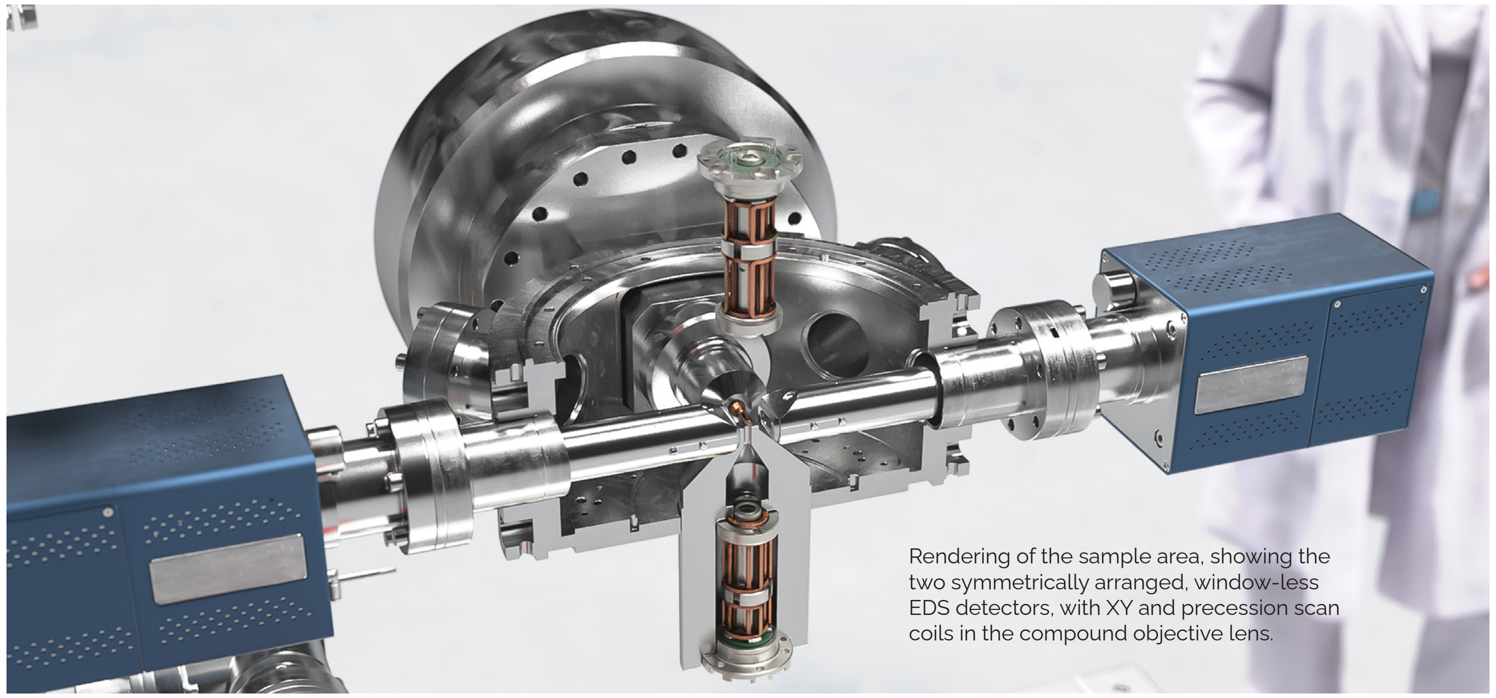
Precession causes the Ewald sphere to rock through reciprocal space, which results in many positives:

- ✔ 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 (ZOLZ and HOLZ) are visible compared to those of a static Ewald sphere;
- ✔ Intensities are integrated through the Bragg condition and are not dominated by complex contrast patterns.

Without dynamical diffraction artifacts, i.e., forbidden reflections, 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 pattern indexing.

Higher order reflections also improve ab initio structure determination of nanocrystalline materials. For structural determination using precession-assisted electron diffraction tomography (3DED with precession, or 3DPED), TESCAN TENSOR offers the optionally available PETS Advanced software, a version of FZU's PETS software (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 (EDX)

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 a 2 steradian solid angle to allow high count rates for measurements such as composition (elemental mapping), EDS tomography, or Virtual STEM to acquire a raw 4D-STEM dataset that not only contains diffraction patterns for each pixel in the dataset, but also an EDS spectrum.

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 vacuum.

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 science, compared to systems with multiple components accreted onto legacy TEM platforms. 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. What's so unique about 4D-STEM is that once you have a scanning diffraction dataset, there are endless possibilities for the information you can extract from it with software analysis and processing. You can map strain and electric field strength with extreme precision. You can map crystal orientation and phase. It is exactly this that we've made transparent to users who are not electron microscope 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. This allows you to interact with your valuable specimen without being held up by complicated setup tasks, and achieve optimized results in the shortest amount of time.

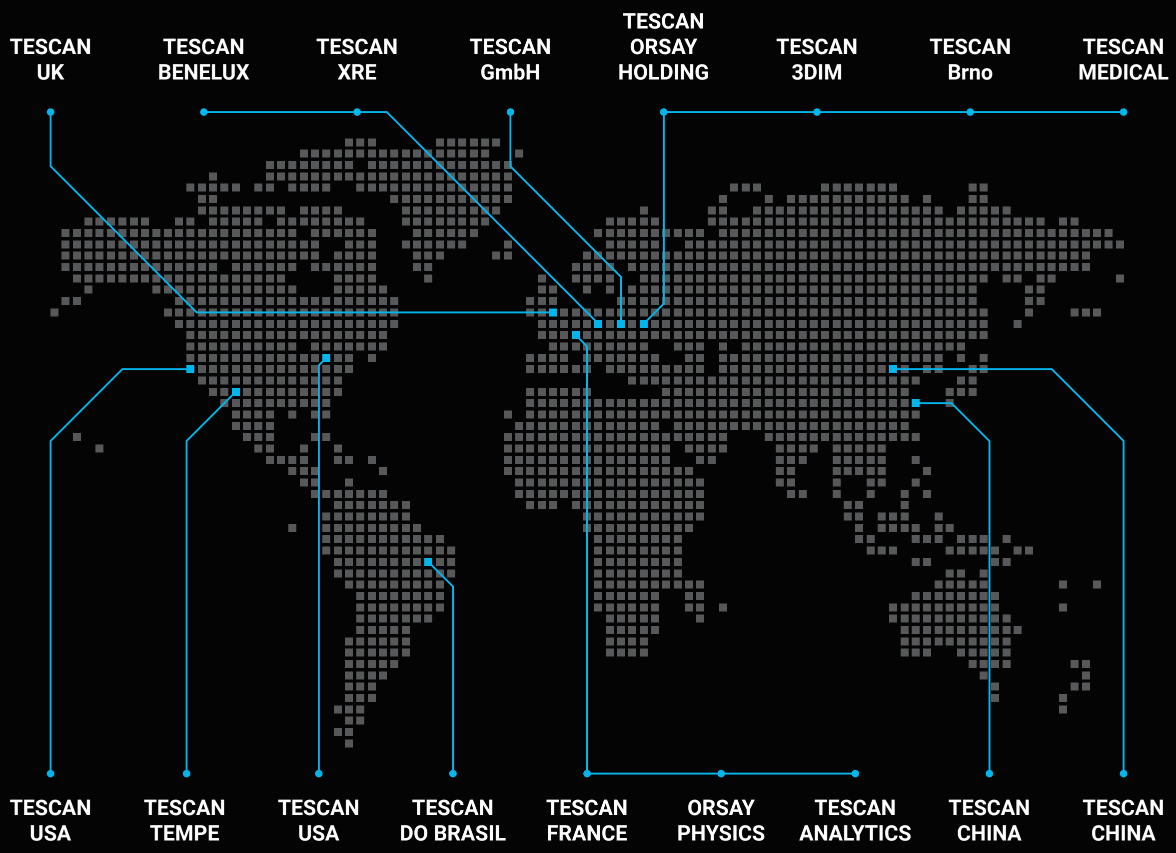
Application-driven design is less an issue with traditional researchers doing fundamental science, but in the growing materials science market, both academic and industrial, we saw there was a desire for "tools" as opposed to "instruments". This is particularly important to ensure that utilization and productivity supports the return on your investment from increasingly complicated scientific instruments purchases.

TESCAN FIB/SEM (Automated) TEM Lamella Preparation Solutions

A comprehensive portfolio of Plasma FIB, Gallium FIB and UHV FIB/SEM platforms, all capable of preparing the highest quality TEM lamella.

Application recommendation:

		Product	Fields	Technology	Applications
Volume characterization		**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.	Materials Science Life Sciences 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.	Semiconductors 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.	Materials Science Life Sciences 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.	Materials Science Semiconductors 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.	Materials Science 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 ORSAY HOLDING was established in 2013 as a result of long-term expansion and establishment of subsidiaries worldwide, including Francebased ORSAY PHYSICS, a world leader in customized focused ion and electron beam technology. TESCAN ORSAY HOLDING maintains its headquarters, production and R&D in Brno, Czech Republic. Every TESCAN microscope is expertly produced in Brno and shipped to customers worldwide.

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