thermoscientific

DATASHEET

Spectra Ultra S/TEM for Advanced Semiconductor Research and Analysis

Our most advanced S/TEM platform for a wide range of semiconductor materials and devices

Semiconductor logic and memory device roadmaps are facing significant inflections and opportunities for innovation. New structures and materials require more accurate characterization of dimensions, stoichiometry, strain, and crystallinity. Samples are increasingly fragile, placing a premium on sample integrity with shorter time-to-data constraints.

The Thermo Scientific™ Spectra™ Ultra S/TEM offers new capabilities to meet these needs. Flexible high-tension switching lets you quickly switch voltages for your specific needs. In addition, the high-performance Thermo Scientific Ultra-X™ Detector shortens elemental mapping time and makes it possible to analyze beam-sensitive structures.

Fast high-tension switching to optimize accelerating voltage

The Spectra Ultra S/TEM features the new S-TWIN’ objective lens, which ensures that the thermal load remains constant at all times. This reduces stage and optics stabilization time from several hours to less than 5 minutes when switching between different accelerating voltages, increasing productivity and unlocking new capabilities.

A typical experiment might start with STEM and energy dispersive X-ray spectroscopy (EDS) mapping of a device, at a lower accelerating voltage, to maximize X-ray yields and reduced sample damage. Subsequently, you can switch to 300 kV to image an interface with the highest achievable imaging resolution. As accelerating voltage can be switched multiple times within a single microscopy session, it is possible to easily optimize the voltage for a specific application. The atomic-resolution EDS maps in **Figure 1** show the reduced “knock-on” specimen damage at a lower kV versus a higher kV.

Key Benefits

Fast high-tension switching. Quickly switch accelerating voltages in a single microscope session to meet your needs: minimize knock-on damage, enhance image contrast, or maximize image resolution.

Efficient chemical analysis. Energy dispersive X-ray spectroscopy on the Spectra Ultra S/TEM provides clean data (<1% spurious peaks) and is faster than other commercially available EDS systems.

Sample integrity. The combination of Ultra-X EDS Detector and fast accelerating voltage switching minimizes knock-on and dose-related damage to beam-sensitive structures.

Repeatable data. Sophisticated software automation routines, such as OptiSTEM+ and OptiMono+ Software, optimize the system for peak performance, resulting in more repeatable and quantifiable data.

High-quality *in situ* and 3D imaging/EDS tomography. Fast cameras, fast EDS detector, smart software, and the wide-gap S-TWIN’ lens enable data acquisition with no compromises on resolution, tilting range, and analytical capabilities.

Configuration flexibility. The Spectra Ultra S/TEM can be configured with several options, such as DPC/iDPC for dopant profile, 4D STEM for strain analysis, and a monochromator for bandgap study.

ThermoFisher
SCIENTIFIC

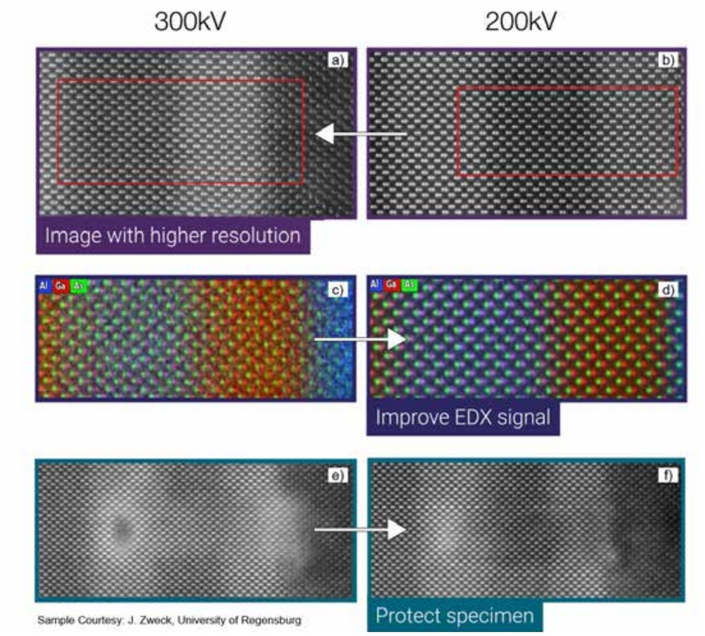

Figure 1. High-angle annular dark-field (HAADF) and EDS maps from an AlGaAs/GaAs interface taken at both 300 kV and 200 kV in less than one hour. Reducing the accelerating voltage reduces specimen damage (e versus f) and improves the EDS signal (c versus d). Specimen courtesy of J. Zweck, University of Regensburg.

More efficient chemical characterization with the Ultra-X EDS Detector

The Spectra Ultra S/TEM introduces the next era in EDS detection with the Ultra-X EDS Detector. Featuring the highest commercially available detector efficiency and a new objective lens design, the Spectra Ultra imaging captures X-rays faster and with higher image quality.

With a solid angle that is two times greater than other EDS detectors, (i.e. >4.45 Sr un-shadowed, 4.04 Sr with a double-tilt analytical holder) the Ultra-X Detector delivers the same quality EDS maps in less time, or better quality maps in the same acquisition time. The spurious peak is less than 1%, comparable to other “cleanest” EDS solutions on the market.

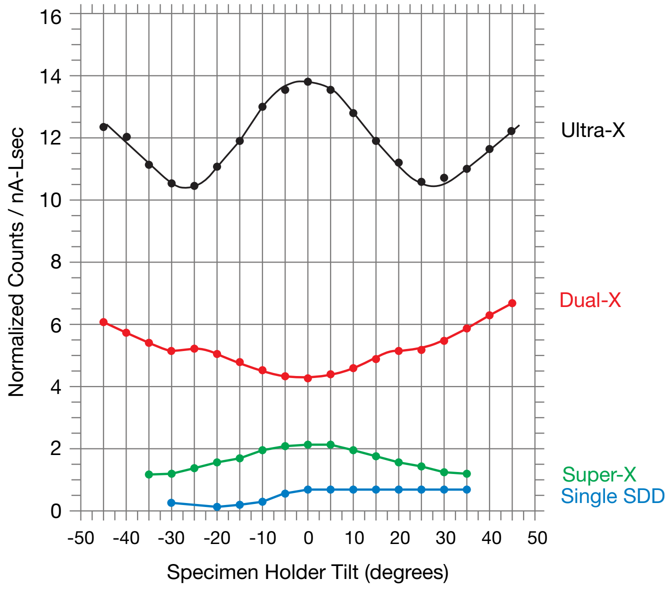

Figure 2. Normalized count rates as a function of tilt angle for a single, Super-X, Dual-X, and the new Ultra-X Detector. Data recorded at 200 kV with optimized specimen holders for each detector configuration. *(Zaluzec, et al., submitted to Microscopy and Microanalysis, 2021.)*

The Ultra-X Detector also provides approximately 2.5× greater sensitivity than the Thermo Scientific Dual-X Detector and 6× greater sensitivity than the Thermo Scientific Super-X™ Detector at zero tilt (**Figure 2**).

The higher sensitivity of the Ultra-X Detector results in higher spectrum imaging quality and lower acquisition times. **Figure 3** shows a comparison of the Dual-X and Ultra-X Detector on a semiconductor specimen with the same acquisition time.

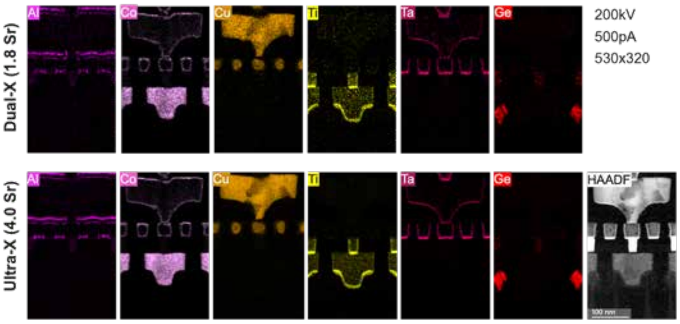

Figure 3. A comparison between Dual-X and Ultra-X EDS maps of a semiconductor device (net intensity). The acquisition time is approximately 260 seconds.

The high sensitivity of Ultra-X Detector also means the same level of chemical information can be obtained with a fraction of the electron dose required by other EDS detector solutions.

Figure 4 compares nitrogen X-ray maps of a 3D NAND sample using Thermo Scientific Velox™ Software at the same experimental conditions. During acquisition, more than 100 frames (5.78 seconds per frame) were collected and the frames were integrated with post-acquisition processing. Comparing the images, the Ultra-X 10-frame map is similar to the Dual-X 50-frame map, and the Ultra-X 50-frame map detail exceeds the detail of the Dual-X 100 frame map.

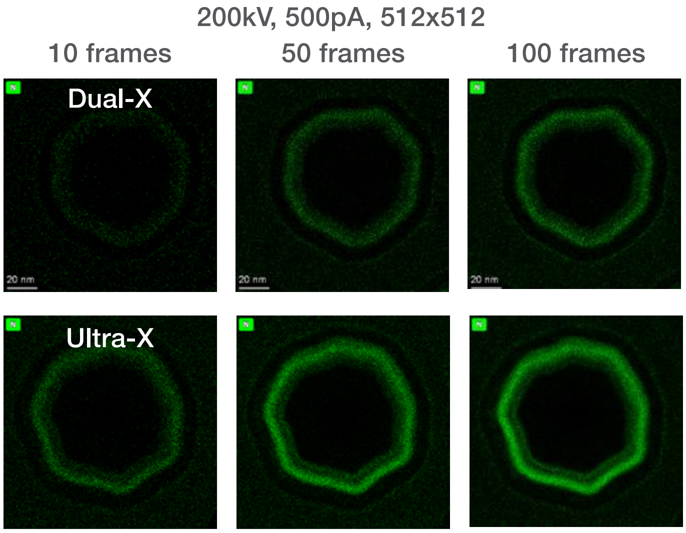

Figure 4. Nitrogen maps from a 3D NAND sample at 10 frames, 50 frames, and 100 frames, obtained with the Dual-X and Ultra-X Detectors.

This expands STEM EDS analysis to more beam-sensitive specimens, enabling faster mapping for more stable specimens.

Atomic-scale analysis for a wide range of devices and materials

With the Spectra Ultra S/TEM, atomic-resolution imaging can be performed with conventional imaging techniques. Spectrum imaging or integrated differential phase contrast (iDPC) imaging can provide atomic-resolution information for an extensive range of materials, including elements such as hydrogen, uranium and compound semiconductors (Figure 5)

The Spectra Ultra S/TEM combines efficient EDS ability, fast accelerating-voltage switching, a large-gap pole piece, and six-fold astigmatism probe correction. These features deliver the industry's leading spatial resolution, efficient analytics, *in-situ* experiment capability and 3D (EDS) tomography in one system.

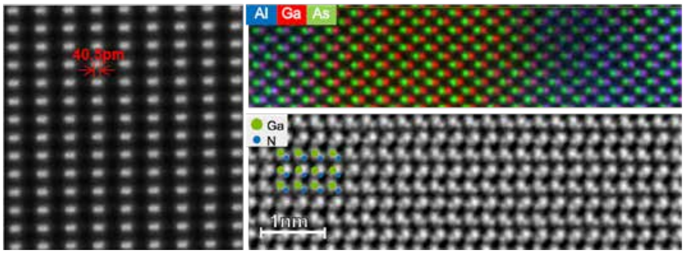

Figure 5. HAADF drift-corrected frame integration (DCFI) STEM image of GaN [212] at 300 kV **(left)**, showing 40.5 pm Ga-Ga dumbbell splitting on a wide-gap pole piece. EDS spectrum imaging of an AlGaAs/GaAs interface using the Ultra-X Detector at 200 kV **(top right)**. GaN [110] imaged with iDPC STEM at 60 kV. Both Ga and N columns are simultaneously revealed **(bottom right)**.

Spectra Ultra S/TEM	Emergy spread*	Information limit	STEM resolution
Probe corrector + X-CFEG	0.4 eV or 0.3 eV**	100 ppm	50 pm (136 pm @ 30 kV) with 100 pA of probe current
Probe + image corrector + X-CFEG	0.4 eV or 0.3 eV**	70 ppm	50 pm (136 pm @ 30 kV) with 100 pA of probe current
Probe + image corrector + X-FEG/Mono	0.2–0.3 eV***	60 ppm	• 50 pm (with 30 pA of probe current) • 125 pm at 30 kV (with 20 pA of probe current)
Probe + image corrector + X-FEG/UltiMono	0.025 eV****	60 ppm	• 50 pm (with 30 pA of probe current) • 125 pm at 30 kV (with 20 pA of probe current)

Note: *All specifications are at 300 kV using an S-TWIN lens (unless otherwise noted)*

** For X-CFEG unless otherwise specified*

*** At reduced extraction voltage*

**** Depending on energy filter options*

***** Specification for 60 kV*

Technical highlights:

Source

- X-CFEG: ultra-high brightness with an intrinsic energy resolution of <0.4 eV. An energy resolution of <0.3 eV is possible with a reduced extraction voltage
- X-FEG Mono: high-brightness Schottky field emitter gun and monochromator with a tunable energy-resolution range down to <0.2 eV
- X-FEG UltiMono: high-brightness Schottky field emitter gun with ultra-stable monochromator and tunable accelerating-voltage energy-resolution range down to 0.025 eV
- Flexible high-tension range from 30 to 300 kVs

Optical column and correctors

- Three-lens condenser system with indicators for convergence angle and the size of the illuminated area, enabling quantitative measurement of electron dose and illumination conditions
- S-CORR probe corrector provides sub-angstrom imaging resolution at 60 kV as specification and an order of magnitude improvement in optical stability. The S-CORR corrects A5 for all accelerating voltages
- New Auto S-CORR CEOS alignment software makes probe-corrector tuning easy, fast, and fully automated up to 5th-order aberrations
- The Thermo Scientific ConstantPower™ Lens and corrector are designed for high thermal stability in accelerating-voltage and mode switches, minimizing image drift
- Low-hysteresis design minimizes crosstalk between optical components for increased reproducibility
- Symmetric S-TWIN' objective lens with a 5.4 mm wide-gap pole-piece design offers "space to do more," enabling the use of special holders, such as heating, cooling, indentation, and electrical probing holders
- The objective aperture is in the back focal plane of the objective lens, optimizing TEM dark-field application work
- Automatic apertures for remote operation and reproducible recall of aperture positions during aperture change
- Rotation-free imaging and free image rotation with stage synchronization in TEM mode allow easy operation and feature alignment
- Deep sub-angstrom resolution for all accelerating voltages (60–300 kV) with low specimen drift
- Field-free imaging in TEM Lorentz mode with 2 nm resolution for magnetic-property studies and an option for Cs-corrected Lorentz with <1 nm resolution
- Integrated Faraday cup and calibrated fluscreen current. Readout is linear over the whole beam-current range

Stage

- Computerized 5-axis, ultra-stable specimen piezo stage for accurate recall of stored positions and tracking of the areas visited during sample navigation. The piezo stage allows for movements as fine as 20 pm to center the feature of interest in the field of view
- Tilt range of ±35 degrees alpha and ±30 degrees beta with the Ultra-X-optimized, analytical double-tilt holder. With the tomography holder, the tilt range is ±70 degrees to minimize the missing wedge in 3D reconstructions

- Linear drift compensation provided by the piezo stage can be used to mitigate limitations caused by thermal drift, which is unavoidable during in-situ heating or cooling experiments

Analytics and detectors

- Ultra-X EDS options, integrated software, and the Gatan Continuum option
- Real-time peak identification and background fitting during ultra-fast EDS acquisition
- Symmetric EDS detector design allows for combined tomographic EDS

EDS detector portfolio

- EDS quantification using Velox Software (featuring dynamic correction of holder shadowing as a function of tilt)
- Ultra-X Detector: high-sensitivity, windowless EDS detector system with high solid angle and high cleanliness
    - Output count rate: up to 1.5 Mcps
    - Energy resolution
        - ≤136 eV for Mn-Kα and 10 kcps (output)
        - ≤140 eV for Mn-Kα and 100 kcps (output)
    - 4.45 srad solid angle (without specimen holder)
    - 4.04 srad solid angle (with analytical double tilt holder)
    - High P/B ratio (Fiori number) >2,500
    - Excellent in-hole performance (<1% hole counts)
    - Low system background in EDS (<1% Fe and Co spurious peaks)

Available detector options

- HAADF detector
- Thermo Scientific Panther STEM Detection System featuring on-axis, solid-state, 8-segmented BF and ADF detectors (16 segments in total)
- Thermo Scientific Ceta™ S or Ceta M Camera (with optional speed enhancement)
- Gatan OneView camera
- Gatan energy filter series
- Electron microscope pixel array detector (EMPAD)

Available holders

- Single tilt holder
- Double tilt holder
- Tomography holder
- Thermo Scientific and third-party *in-situ* holders
- Please ask for a list of functional holders

Software

- Differential phase contrast (DPC) STEM technique enables real-time measurement of intrinsic magnetic and electric fields
- Integrated DPC (iDPC) software for high STEM image contrast of materials across the whole periodic table. This low-dose technique replaces annular bright field as the technique of choice for light elements. Invaluable when applied to samples that are typically damaged under short exposures to the electron beam
- OptiSTEM+ Software for single-click correction of 1st and 2nd order probe-forming aberrations, without the need to change to a standard test sample. OptiSTEM+ Software allows you to obtain optimized STEM resolution on all our probe-corrected tools regardless of experience level
- OptiMono+ Software for completely automated monochromator alignment and tuning to the highest achievable energy resolution on monochromated systems
- Fully digital system for remote operation using the SmartCam suite
- Advanced, integrated software enables fast and simultaneous signal acquisition (up to five STEM signals)

Other features

- Environmental enclosure to relax the acoustic and room-temperature variation requirements
- Cold trap design maximizes uptime with up to three days of operation

Installation requirements

- Please contact your sales representative for a complete pre-installation requirements document

Find out more at **thermofisher.com/spectra-ultra**

ThermoFisher
SCIENTIFIC

For current certifications, visit thermofisher.com/certifications. DS0369-EN-07-2021