

# Helios 5 PFIB CXe DualBeam for Battery Research

## Enabling microstructural and analytical characterization of battery materials

The Helios 5 PFIB CXe DualBeam delivers exceptional capabilities for large-area 2D and 3D characterization in battery development.

The Thermo Scientific™ Helios™ 5 PFIB CXe DualBeam is part of the fourth generation of the industry-leading Helios DualBeam family. It combines a new plasma focused ion beam (PFIB) column with the monochromated Thermo Scientific Elstar™ Electron Column to deliver advanced focused-ion and electron beam performance. With a flexible stage that allows for a variety of sample sizes, weights, and accessories, this instrument provides a high level of insight into interfaces and 3D structures in battery materials.

The PFIB delivers exceptional performance at all operating conditions, enabling you to perform a wide range of challenging and demanding tasks at the micro scale. The Helios 5 PFIB CXe DualBeam is an all-in-one instrument; there is no need to choose between ion columns (each of which might only be suited for limited applications) and there is no requirement for complex accessories that improve cut-face quality (e.g. milling curtain mitigation). The innovative Elstar Electron Column with high-current UC+ technology provides extreme high-resolution imaging and high materials contrast. The latest chemistries developed by Thermo Fisher Scientific are available via the optional Thermo Scientific MultiChem™ or GIS Gas Delivery Systems, further enhance milling throughput, precision, and control.

In addition to advanced electron and ion optics, the Helios 5 PFIB CXe DualBeam incorporates a suite of state-of-the-art software that enables simple and consistent sample preparation for high-resolution (scanning) transmission electron microscopy (TEM/STEM) and atom probe tomography (APT), as well as high-throughput and quality for large-volume subsurface and 3D characterization, even on challenging samples.

### Key Benefits

High-quality Ga+ free TEM sample preparation thanks to a novel PFIB column, which enables 500 V Xe+ final polishing and delivers excellent performance at all operating conditions

Fast and easy, automated, multisite *in situ* and *ex situ* TEM sample preparation and cross-sectioning using optional AutoTEM 5 Software

High-throughput and exceptional quality for statistically relevant 3D characterization, cross-sectioning and micromachining using a next-generation 2.5 μA xenon PFIB column

Access high-quality, multi-modal subsurface and 3D information with precise targeting of your region of interest using optional Auto Slice & View 4 Software

Fast access to nanoscale information with SmartAlign and FLASH technologies for users of any experience level

Reveal nanoscale details using the Elstar Electron Column with high-current UC+ monochromator technology, enabling sub-nanometer performance at low energies

Complete sample information with sharp, refined, and charge-free contrast obtained from up to six integrated in-column and below-the-lens detectors

Advanced capabilities for electron- and ion-beam induced deposition and etching with optional MultiChem or GIS Gas Delivery Systems

Precise sample navigation tailored to individual application needs thanks to the high-flexibility 110 mm stage and optional in-chamber navigational camera

Artifact-free imaging based on integrated sample cleanliness management and dedicated imaging modes such as SmartScan and DCFI

### High-quality large-volume subsurface and 3D analysis

Subsurface or 3D characterization is often required to better understand the material properties of a sample. In many cases, large volumes, inaccessible by conventional Ga+ FIB instruments, are necessary to obtain representative and relevant results. The excellent high-current performance of the Helios 5 PFIB CXe DualBeam, combined with optional Thermo Scientific Auto Slice & View™ 4 Software, enables high-quality, fully automated acquisition of large volume 3D datasets in a multitude of modalities, including: BSE imaging for maximum materials contrast, energy dispersive spectroscopy (EDS) for compositional information, and electron backscatter diffraction (EBSD) for microstructural and crystallographic information. Combined with Thermo Scientific Avizo™ Software for visualization, it delivers a unique workflow solution for high-resolution, advanced 3D characterization and analysis at the nanometer scale.

### High-quality Ga+ free TEM sample preparation

To understand new materials or to find the root cause of failures, scientists and engineers constantly face new challenges that require highly localized characterization of increasingly complex samples with ever smaller features. The latest technological innovations of the Helios 5 PFIB CXe DualBeam, in combination with easy-to-use, comprehensive software and our application expertise, enable fast and easy preparation of site-specific, high-quality samples for high-resolution (S)TEM from a wide range of materials. In order to achieve high-quality results, final polishing with low-energy ions is required in order to minimize surface damage on the sample. Our new PFIB column not only delivers high-resolution imaging and milling at high voltages, it now extends PFIB performance to accelerating voltages as low as 500 V, enabling the creation of exceptionally high-quality, ultra-low-damage TEM lamella.

The combination of the Helios 5 PFIB CXe DualBeam with Thermo Scientific AutoTEM™ 5 Software enables automated *in situ* TEM sample preparation. This allows users of any experience level to achieve high-quality results and significantly increases productivity through unattended sample preparation during the day or overnight.

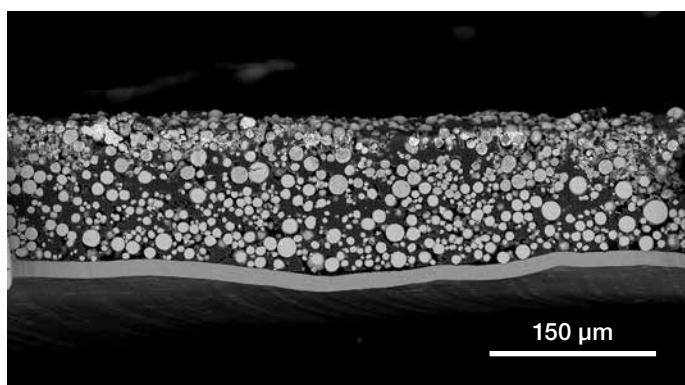


Figure 2. 600  $\mu\text{m}$  wide cross section of battery cathode.



Figure 1. Helios 5 PFIB CXe DualBeam.

### High-resolution with precise materials contrast

The Helios 5 PFIB CXe DualBeam features an ultra-high-brightness electron source with next-generation UC+ monochromator technology, reducing the beam energy spread below 0.2 eV for beam currents up to 100 pA. This enables sub-nanometer resolution and the excellent surface sensitivity at low landing energies. The innovative Elstar Electron Column serves as the foundation of the system's unprecedented high-resolution imaging capability. It can reveal nanoscale details across a wide range of working conditions, whether operating at 30 keV (to access structural information) or at lower energies (to obtain charge-free, detailed information from the surface).

With its unique detection system located inside the column, along with an immersion mode, the system is designed for simultaneous detector acquisition for angular and energy-selective secondary-electron (SE) and backscattered-electron (BSE) imaging. Fast access to detailed nanoscale information is available, not only top-down, but also on tilted specimens or cross-sections. Additional below-the-lens detectors and an electron beam deceleration mode ensure fast, easy, and simultaneous collection of all signals to reveal even small features in material surfaces or cross sections. Fast, accurate, and reproducible results are obtained thanks to the unique design of the Elstar Column, which includes advanced auto alignments, constant power lenses for higher thermal stability, and electrostatic scanning for higher deflection linearity and speed.

The Helios 5 PFIB CXe DualBeam introduces novel SmartAlign technology, which eliminates the need for any user alignments of the electron column. This not only minimizes maintenance, but also increases your productivity. Generally, to achieve the best results on different materials, fine tuning of the beam would be required. This typically consists of an alignment

sequence (focusing, lens centering, stigmatism) that can be challenging and time consuming. To address this, the Helios 5 PFIB CXe DualBeam introduces FLASH technology, a new image fine-tuning capability. With FLASH technology, you only need to perform a simple mouse-gesture in the graphical user interface, a procedure similar to image focusing, and the

## Specifications

### Electron optics

- Extreme high-resolution field emission Elstar Electron Column with:
  - Magnetic immersion objective lens
  - High-stability Schottky field emission gun that provides stable, high-resolution analytical currents
  - UC+ monochromator technology
- User-alignment-free SmartAlign technology
- 60-degree dual objective lens with pole-piece protection allows for tilting of larger samples
- Automated heated apertures ensure cleanliness and touch-free aperture exchange
- Electrostatic scanning for higher deflection linearity and speed
- Thermo Scientific ConstantPower™ Lens for high thermal stability
- Integrated fast beam blanker\*
- Beam deceleration with stage bias from 0 V to -4 kV\*
- Minimum source lifetime: 12 months

### Electron beam resolution

- At optimum working distance (WD):
  - 0.7 nm at 1 kV
  - 1.0 nm at 500 V (in-column detector)
- At coincident point:
  - 0.6 nm at 15 kV
  - 1.2 nm at 1 kV

### Electron beam parameter space

- Electron beam current range: 0.8 pA to 100 nA
- Accelerating voltage range: 350 V to 30 kV
- Landing energy range: 20 eV\* to 30 keV
- Maximum horizontal field width: 2.3 mm at 4 mm WD

### Ion optics

High-performance PFIB column with inductively-coupled Xe+ plasma (ICP)

- Ion beam current range: 1.5 pA to 2.5  $\mu$ A
- Accelerating voltage range: 500 V to 30 kV
- Maximum horizontal field width: 0.9 mm at beam coincidence point

Ion beam resolution at coincident point

- <20 nm at 30 kV using preferred statistical method
- <10 nm at 30 kV using selective edge method

### Detectors

- Elstar in-lens SE/BSE detector (TLD- SE, TLD-BSE)
- Elstar in-column SE/BSE detector (ICD)\*
- Everhart-Thornley SE detector (ETD)
- IR camera for viewing sample/column
- High-performance in-chamber electron and ion detector (ICE) for secondary ions and electrons

instrument will introduce any necessary corrections “on-the-fly” to the stigmatizers and lens centering, while also bringing the image into focus. On average, FLASH technology can result in an up to a 10x improvement in the time required to obtain an optimized image.

- In-chamber Thermo Scientific Nav-Cam Sample Navigation Camera\*
- Retractable low-voltage, high-contrast directional solid-state backscatter electron detector (DBS)\*
- Integrated beam current measurement

### Stage and sample

Flexible 5-axis motorized stage

- XY range: 110 mm
- Z range: 65 mm
- Rotation: 360° (endless)
- Tilt range: -38° to +90°
- XY repeatability: 3  $\mu$ m
- Max sample height: 85 mm clearance to eucentric point
- Max sample weight at 0° tilt: 5 kg (including sample holder)
- Max sample size: 110 mm with full rotation (larger samples possible with limited rotation)
- Compucentric rotation and tilt

### Vacuum system

- Complete oil-free vacuum system
- Chamber vacuum: <2.6  $\times$  10<sup>-6</sup> mbar (after 24 h pumping)
- Evacuation time: <5 minutes

### Chamber

- Electron- and ion-beam coincidence point at analytical WD (4 mm SEM)
- Ports: 21
- Inside width: 379 mm
- Integrated plasma cleaner

### Sample holders

- Standard multi-purpose holder, uniquely mounts directly onto the stage, hosts up to 18 standard stubs (Ø12 mm), three pre-tilted stubs, cross-section samples, and two pre-tilted row-bar holders\* (38° and 90°); does not require tools to mount a sample
- Each optional row-bar accommodates 6 (S)TEM grids
- Vise specimen holder to clamp irregular, large, or heavy specimens to the specimen stage\*
- Universal mounting base (UMB) for stable, flexible mounting of many sample and holder combinations such as flat and pretilt stubs, or row holders for TEM grids\*
- Various wafer and custom holder(s) available by request\*

### Image processor

- Dwell time range from 25 ns/pixel to 25 ms/pixel
- Up to 6144  $\times$  4096 pixels
- File type: TIFF (8, 16, 24-bit), BMP, or JPEG standard
- SmartScan (256 frame average or integration, line integration and averaging, interlaced scanning)
- DCFI (drift compensated frame integration)

## System control

- 64-bit GUI with Windows® 10, keyboard, optical mouse
- Up to four live images showing independent beams and/or signals. Live color signal mixing
- Local language support: check with your local Thermo Fisher Sales representatives for available language packs
- Two 24-inch widescreen monitors (1920 x 1200 pixels) for system GUI and full-screen image
- Microscope-controlling and support computers seamlessly share one keyboard, mouse, and monitors
- Joystick\*
- Multifunctional control panel\*
- Remote control and imaging\*

## Supporting software

- “Beam per view” graphical user interface, with up to 4 simultaneously active quads
- Thermo Scientific SPI (simultaneous FIB patterning and SEM imaging), iSPI (intermittent SEM imaging and FIB patterning), iRTM (integrated real time monitor), and FIB immersion mode for advanced, real-time SEM and FIB process monitoring and endpointing
- Patterns supported: lines, rectangles, polygons, circles, donuts, cross-sections, and cleaning cross-sections
- Directly import BMP files or stream files for 3D milling and deposition
- Material file support for “minimum loop time,” beam tuning and independent overlaps
- Image registration enables sample navigation in an imported image
- Sample navigation possible on an optical image

## Accessories\*

- GIS (gas injection system) solutions
  - Single GIS: up to four independent units for enhanced etching or deposition
  - MultiChem Gas Delivery System: up to six chemistries on the same unit for advanced etching and deposition controls
- GIS beam chemistry options\*\*
  - Platinum deposition
  - Tungsten deposition
  - Carbon deposition
  - Insulator deposition II
  - Gold deposition
  - Enhanced Etch (iodine, patented)
  - Insulator enhanced etch (XeF2)
  - Delineation Etch (patented)
  - Dx Delaying
  - Empty crucibles for user-supplied materials approved by Thermo Fisher Scientific
  - More beam chemistries available upon request

- Thermo Scientific EasyLift™ Nanomanipulator - fully integrated for precise *in situ* sample manipulation
- FIB charge neutralizer
- Analysis: EDS, EBSD, WDS
- Thermo Scientific QuickLoader™ Load Lock for fast sample exchange without breaking system vacuum
- Cryo-solutions for DualBeam
  - Exclusive Thermo Scientific CryoMAT Loader for cryogenic material science applications
  - Solutions from external vendors
- Thermo Scientific acoustic enclosure
- Thermo Scientific CryoCleaner

## Software options\*

- AutoTEM 5 Software for automated (S)TEM sample preparation
- Thermo Scientific AutoScript™ 4 Software: advanced automation suite for DualBeams
- Thermo Scientific Maps Software for automatic acquisition of large images and optional correlative work
- Thermo Scientific NanoBuilder™ Software – advanced proprietary CAD-based (GDSII) solutions for FIB and beam deposition, optimized for nanoprototyping of complex structures
- Auto Slice & View 4 Software – automated sequential milling and viewing lets you collect a series of slice images as well as EDS or EBSD maps for 3D reconstruction
- Avizo Software – 3D reconstruction and analysis software
- CAD navigation

## Warranty and training

- 1 year warranty
- Choice of service maintenance contracts
- Choice of operation/application training contracts

## Documentation and support

- Online user guidance
- User operation manual
- Prepared for RAPID remote diagnostic support

\* *Optional*

\*\* *Some beam chemistries may only be available on MultiChem or single GIS*

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