

# Unlocking TEM preparation precision, efficiency, and robustness

## with the Helios 6 HD FIB-SEM's automation workflows

### What you need to know about high-volume, scalable TEM preparation

High-volume TEM preparation demands more than automation, it requires precision that scales, stability across shifts, and repeatability across dozens of sites. The Thermo Scientific™ Helios™ 6 HD FIB-SEM with AutoTEM™ 6 Software is engineered to transform lamella preparation from an operator-dependent process into a controlled, multi-site, volume production-ready workflow. By combining high-accuracy stage control, automated template execution, intelligent lift-out management, and automated FIB alignments, the system enables consistent lamella quality, reduced intervention, and predictable throughput across extended runs.

### High-volume TEM preparation challenges

Laboratories face increasing pressure to deliver higher volumes of high-quality TEM lamellae with fewer skilled operators.

Traditional workflows can be limited by:

- Manual alignment variability across samples
- Site registration loss during stage navigation
- Needle wear and lift-out attachment failure
- Drift and beam stability issues during extended runs
- Throughput bottlenecks during multi-site processing

To meet modern failure analysis and process development demands, automated TEM preparation must deliver repeatable targeting, stable operation across kV transitions, and consistent lamella handoff for final polishing, all without constant operator supervision. By adopting automated TEM-prep workflows with the Helios 6 HD FIB-SEM, a TEM analysis lab expects to yield higher sample output with reduced operating cost.

The Helios 6 HD FIB-SEM is an advanced focused ion beam (FIB) and scanning electron microscope (SEM) designed for precise material analysis and sample preparation. Together with

AutoTEM 6 Software for lamella prep automation, the instrument streamlines setup and execution while maintaining tight control over alignment and endpointing. In practice, these capabilities emphasize accurate targeting, efficient multi-site processing, and repeatable low-kV thinning to sustain consistent lamella quality across runs.

The necessary sample volume for design validation and root cause fault analysis requires improvements in automated TEM prep repeatability. As node sizes shrink, samples must be extremely thin, consistently produced, and free of artifacts. The Helios 6 HD FIB-SEM and AutoTEM 6 Software workflow positions features with high accuracy, thins and polishes with controlled low-kV conditions, and maintains stable operation over long routines. This combination reduces rework and operator intervention while keeping outcomes consistent across diverse devices.

To demonstrate performance, this document walks through the automated lift-out and pre-thinning of a TEM lamella using AutoTEM 6 Software with manual final polishing to achieve the target lamella thickness. Utilizing a manually deprocessed, commercially available Apple A12 chip, the process isolates the finFETs (fin field effect transistors).

### Required items

- Helios 6 HD FIB-SEM
- AutoTEM 6 Software

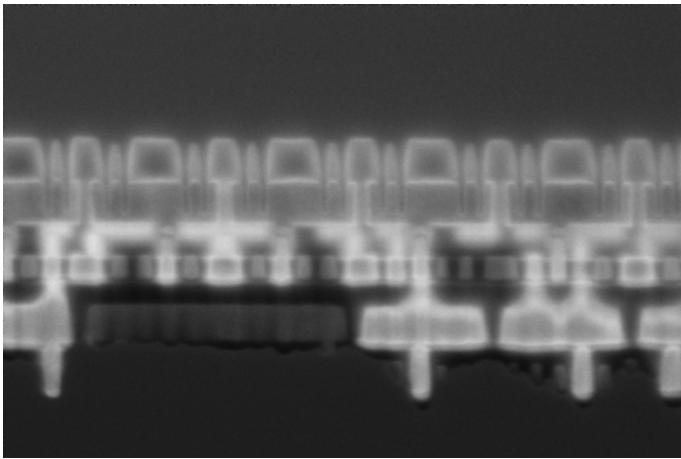


Figure 1. SEM image of A12 7 nm process node finFET transistors automatically thinned on Helios 6 HD with AutoTEM 6 software. Note the structure is inverted, with the Si substrate at the top, and the metal layers at the bottom.

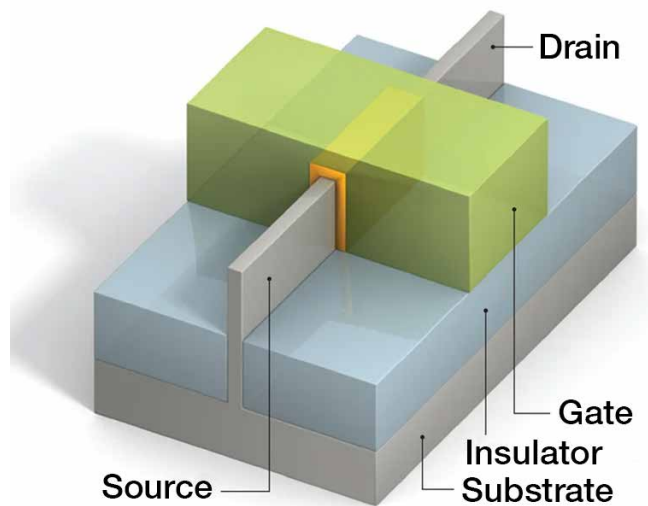


Figure 2. FinFETs (Fin Field Effect Transistors) are three dimensional transistors that form the basis for modern nanoelectronic semiconductor devices. In a finFET, transistors are positioned at the bottom layers of the chip, with metal layers stacked above and silicon substrate beneath. The source/drain region forms the fins, running perpendicular to the gate. Source: <https://www.powerelectronicsnews.com/understanding-finfet-technology-a-comprehensive-guide/>

### Solution tools

|  | Precision | Productivity | Robustness | Auto Preparation | Auto Milling | Auto Lift-out | Auto/Manual Thinning |
|--|-----------|--------------|------------|------------------|--------------|---------------|----------------------|
| Auto TEM 6 Enhanced Software           | ●         | ●            | ●          | ■                | ■            | ■             | ■                    |
| Improved MultiChem stability           |           |              | ●          |                  | ■            | ■             | ■                    |
| High-accuracy stage movement           | ●         | ●            | ●          |                  | ■            | ■             | ■                    |
| High-accuracy grid flipping            | ●         |              | ●          |                  |              | ■             | ■                    |
| New EasyLift design and sharpening     | ●         | ●            | ●          |                  |              | ■             |                      |
| New grid holder and management         |           | ●            | ●          |                  |              | ■             | ■                    |
| Automated blind thinning               | ●         | ●            |            |                  |              |               | ■                    |
| New digital scan engine                | ●         |              | ●          | ■                | ■            | ■             | ■                    |
| New Osprey FIB columns                 | ●         | ●            | ●          |                  | ■            |               | ■                    |
| Reduced amorphous surface damage       | ●         | ●            |            |                  |              |               | ■                    |
| New automated preventative maintenance | ●         |              | ●          | ■                | ■            | ■             | ■                    |

Figure 3. New and improved solution tools provided by Helios 6 HD hardware and AutoTEM 6 software.

An integrated set of capabilities in the Helios 6 HD FIB-SEM and AutoTEM 6 Software maintains alignment, reduces manual effort, and keeps performance steady from setup through final polishing, advancing precision, productivity, and robustness across the workflow.

In preparation, AutoTEM 6 Software templates coordinate fiducials, grounding, and site tracking, while the Digital Scan Engine provides low noise imaging with fine scan rotation for clean overlay alignment. The Thermo Scientific MultiChem Gas Delivery System (GIS) delivers uniform FIB-SEM deposits with

quick thermal recovery, and the High Accuracy Stage preserves registration during rapid tilts and rotations.

During milling, the Osprey FIB column supplies a stable beam from 30 kV down to low kV for predictable trenching, undercuts, and cleanup, with the Digital Scan Engine keeping patterns tightly oriented to device features. Consistent protective caps from MultiChem GIS deposition and fine step size motion from the stage shorten reacquisition after geometry changes, sustaining smooth progression across multiple sites.

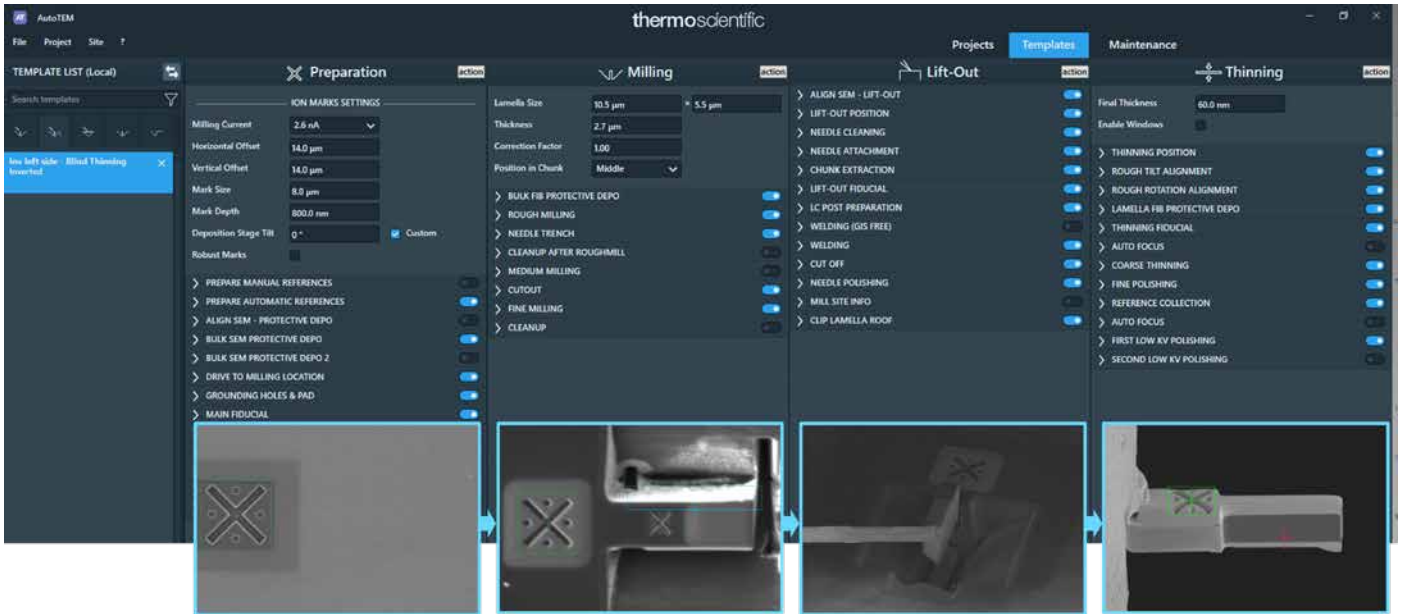


Figure 4. An AutoTEM Software template for inverted lift out with example process images. All activities can be expanded and adjusted to fit any use case.

For lift out, AutoTEM Software automatically inspects and sharpens the EasyLift Nanomanipulator needle to preserve weld quality and to extend tip life. Automated Grid Management identifies viable landing positions and auto selects the first available post, while the Dual Lamella Carrier Holder enables high accuracy grid flipping so a chunk landed horizontally is quickly reacquired vertically without losing post registration.

In thinning and final polishing, the High Accuracy Stage and Digital Scan Engine establish lamella face parallelism and orientation before dose based pre thinning. The Osprey column remains stable across kV transitions, and optimized low kV operation achieves reduced amorphous surface damage, supporting clear results after manual endpointing with simultaneous patterning and imaging (SPI), intermittent simultaneous patterning and imaging (iSPI), or FIB immersion

modes. Across shifts, automated preventative maintenance and condition specific beam alignments keep the instrument ready for unattended or supervised runs.

## AutoTEM 6 Software project initialization

On the bulk stage, navigate to the region of interest in the Nav Cam quad. Select “Horizontal bulk” to enter Holder Regions. Intelligent axis limits in Holder Regions enable rapid movement in XYZ, tilt, and rotation while preventing collisions and touch alarms, sustaining repeatable site-to-site navigation and lowering recovery events to improve overall throughput and stability. The High-Accuracy Stage Movement maintains registration across tilts/rotations for reliable overlay placement.

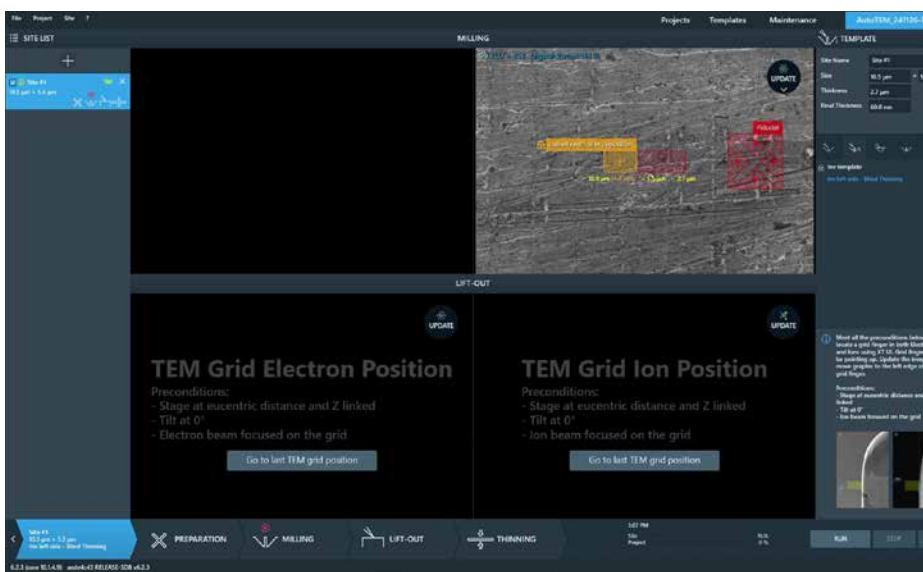


Figure 5. AutoTEM Software project during initialization. The Site List is on the left and the Template List is on the right, with an inverted template selected. The top right quad shows the sample surface with the chunk overlay and fiducial.

Create a new project. AutoTEM Software automatically initializes site #1. Templates are available for top-down, inverted, and planar lift-outs, as well as in situ cross-sectioning. This example uses the inverted template, which is optimal when the feature of interest is deepest within the sample (e.g., finFETs against the silicon substrate). Templates are fully modifiable, and stateful site tracking with step-wise activity execution preserves progress across interruptions, enabling continuous multi-site operation in supervised or unattended modes. Automated Preventative Maintenance (scheduled FIB alignments and health checks) can be used between batches to keep automation predictable.

Select a template from the right-hand pane (top down ex situ, inverted ex situ, planar ex situ, in situ thinning, in situ cross section). Default templates and user-modified templates can be selected. In the upper right AutoTEM quad, click Update to snapshot the lift-out location. The icon indicates whether SEM or FIB is used, dictated by the template.

If the exposed sample surface is fragile (e.g., FEOL wafer coupons), SEM-deposited carbon and tungsten can be applied automatically over the region of interest (ROI) prior to any ion exposure.

The lift-out overlay appears, showing the layout of the chunk. Position the overlay over the ROI, adjusting the orange region to resize the deposition-protected area. The red section is the future weld area to the Lamella Carrier post, leaving room for the Thinning Fiducial and a clear lamella window offset from the post. The red X marks the Site Fiducial used to align all bulk stage movements and FIB patterns. This persistent reference stabilizes downstream placement across tilts and rotations, improving registration and reducing reacquisition time.

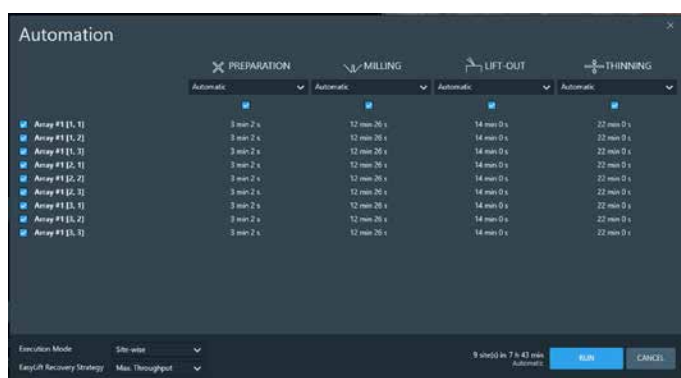


Figure 6. AutoTEM Software Site List overview with 9 sites populated.

Add more sites by navigating to new positions on the bulk stage and clicking + in the Site List. Arrays of sites can be created with defined column and row pitches and rotations. This allows easy initialization of batch lamella lift-outs.

Click Run to open the site overview. Run all sites to completion or stagger processing by disabling specific sites and/or template activities. If a site is partially completed, AutoTEM Software remembers progress and resumes with correct conditions and positioning.

For each activity segment (Preparation, Milling, Lift Out, Thinning), choose Automatic, Automatic (with manual fall back), or Guided mode. Automatic runs start to finish, skipping failed sites. Automatic (with manual fall back) pauses for operator intervention. Guided walks you through the process step by step. Change the Execution Mode to Site Wise or Step Wise site processing, dictating whether AutoTEM Software will complete a single site entirely before processing the next site or complete activity groups for all sites in succession. Adjust the EasyLift

Recovery Strategy to define chunk handling on irrecoverable errors. Max Throughput removes the chunk to proceed to the next site; Max Safety pauses to allow manual recovery.

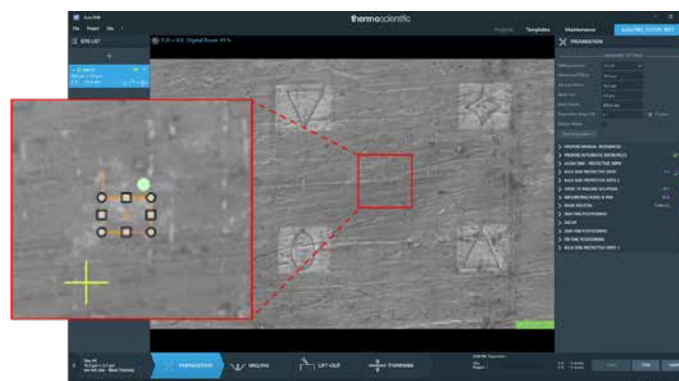


Figure 7. Automatic drift corrected SEM deposition on the ROI.

## Preparation

After clicking Run, AutoTEM Software will execute the predefined template automatically. From this point forward, no monitoring or adjustments are required. If manual fall back is enabled, you may observe progress and confirm prompts when requested.

### Ion-free SEM deposition

When enabled, SEM carbon and tungsten deposition are applied over the ROI prior to FIB exposure. Four ion marks are milled far from the ROI for SEM reference, and repeated SEM scans of these marks place the deposition pads precisely over the ROI, compensating for any beam drift. This referential SEM deposition preserves the ROI from early surface ion damage. MultiChem GIS stability provides consistent deposition thickness with quick thermal recovery during batch operation.

With the ROI protected, the stage tilts to 52° (normal to the FIB). Grounding holes are milled adjacent to the ROI and filled with tungsten to alleviate charging effects on the bulk surface. The Site Fiducial is created at the same location and used to coordinate fine stage movements and milling tasks. Local grounding reduces charging-induced image shifts, while the fiducial anchors pattern registration throughout the routine.

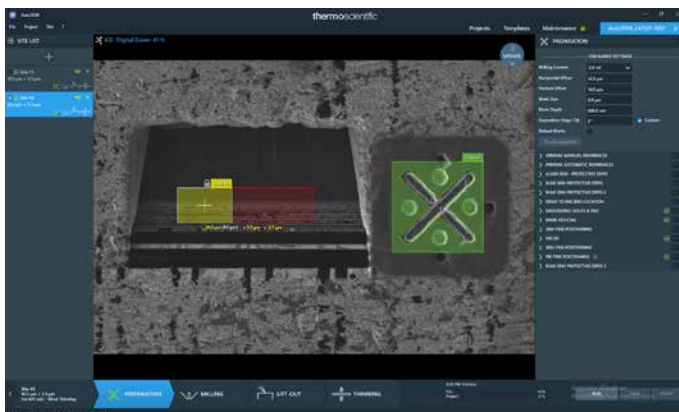


Figure 8. Decapping at a shallow angle exposes buried features. The chunk is lifted from within the trench.

## Decapping and deprocessing

If upper sample structures obscure the feature of interest, AutoTEM Software can perform decapping or deprocessing to secure well-placed lift-out. Decap mills a shallow-angled trench at the ROI, exposing buried features so the chunk can be lifted out closer to the target depth at the precise feature location. Deprocessing mills an angled trench beside the ROI, exposing the feature cross-section from the side. The chunk is then lifted out adjacent to the trench, preserving full sample height. Both methods expose structures for direct targeting, minimize overburden carried into the chunk, and shorten downstream endpointing. DDE's fine scan rotation aids shallow-angle alignment and clear visualization.

### Outcome

Establish registration, protect sensitive structures, and anchor downstream automation. By coordinating fiducials, grounding, and drift-compensated deposition, the system creates a controlled starting condition that reduces variability and improves repeatability across multiple sites.

## Milling

AutoTEM Software deposits FIB tungsten on the ROI, then mills away surrounding bulk material to free the chunk in X and Y. The stage tilts down to 0° to expose the side and performs the J cut under the ROI to free the chunk in Z. The system returns to 52° for fine milling to remove any redeposition. The chunk becomes free-floating, held only by a small tab of bulk material. Geometry-aware trenching with needle clearance and a controlled undercut limit redeposition and accidental reattachment, improving lift-out consistency and reducing rework. Protective caps and weld surfaces benefit from MultiChem GIS's steady output.

## Lift out

The EasyLift Nanomanipulator is inserted away from the sample, and the convolutional neural net inspects the tungsten needle for debris. If needed, AutoTEM Software mills away excess material and sharpens the tip. This EasyLift Nanomanipulator lift-out and sharpening method helps maintain weld quality and helps extend usable needle life.

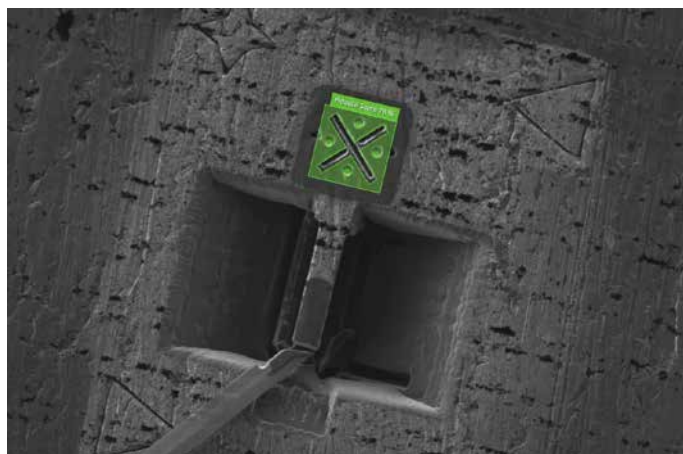


Figure 9. AutoTEM Software during chunk lift-out demonstrating the angle of attack for the new inverted landing geometry.

Using the Site Fiducial as reference, AutoTEM Software lowers the EasyLift Nanomanipulator into the needle trench to abut the chunk. The MultiChem GIS is inserted to flow tungsten gas, and the needle is welded to the chunk. The remaining tab of bulk connecting material is milled away, and the chunk is lifted free from the surface.

The stage moves to a Dual Lamella Carrier Holder (DLCH) and identifies an unoccupied Lamella Carrier (LC) post using the neural net. Automated Grid Management maps viable landing positions and automatically populates the first available side-of-post location. The Lift Out Fiducial is milled on the post to serve as a general reference for movement, milling, and deposition. The side of the post is planed flat, and the chunk is welded to the post. The new inverted lift-out geometry lands the chunk on the left side of the post, providing a perpendicular FIB view and minimizing needle consumption. Substantially reducing needle waste extends time between needle replacement service actions and maintains reliable extraction performance. With a mix of lift-out orientations (top-down, inverted, planar), typical performance averages dozens of chunks before sharpening is required, and utilizing more of the inverted method increases that number.

With the sample inverted on the LC post, the silicon substrate is milled square, perpendicular to the chunk face, in preparation for thinning.

### Outcome

Automated trenching and undercut strategies free the chunk efficiently, minimizing redeposition and unintended reattachment and improving lift-out success rate. Neural network-assisted needle conditioning sustains weld quality while reducing consumption. High-accuracy flipping preserves registration, enabling repeatable chunk placement.

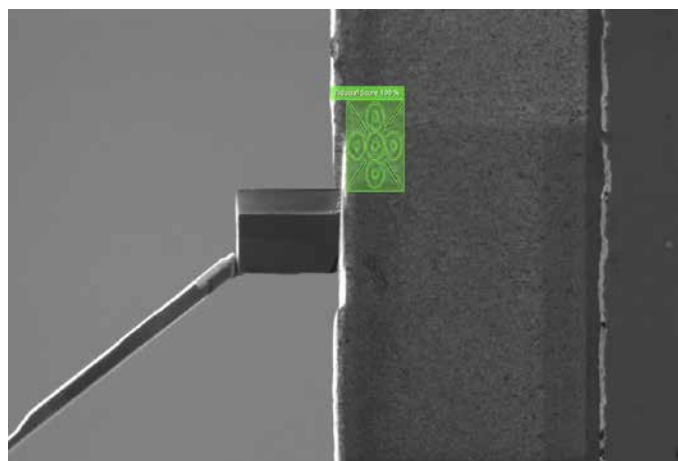


Figure 10. AutoTEM Software welding the chunk to the Lamella Carrier post.

# Thinning

## Pre-thinning

Automatic Quick Flip (AQF) rotates the DLCH from horizontal to vertical in chamber without the need for unloading. High Accuracy Grid Flipping preserves post registration across the flip, enabling fast reacquisition of the chunk location. In vertical orientation, the FIB is now aligned with the silicon substrate.

AutoTEM Software incrementally tilts and rotates the stage to find the most upright and straight alignment of the chunk, improving face parallelism before thinning. This establishes a reliable starting geometry, reducing beam rotation adjustments during endpointing. A tungsten cap is deposited on the silicon for mechanical stabilization. A small Thinning Fiducial is milled near the post for stage movement reference and pattern placement during thinning. With the chunk aligned and stabilized, the front and rear faces are cleaned to expose the internal structures. The lamella is now ready for automated inverted pre-thinning and final manual endpointing.



Figure 11. Completed chunk alignment and rough milling.

## Blind dose based thinning

AutoTEM Software performs blind thinning with controlled over-tilt to compensate for beam profile. A 30 kV cleaning cross-section mills the front face to a dose-defined depth. The same process is repeated on the rear face. Now ~120 nm in thickness, the lamella over-tilt is increased slightly to further expose the front face. A 5 kV box pattern removes additional material and high- kV amorphous damage on the lamella rear face. The same is repeated on the front face. The example lamella is finished with 5kV thinning, at ~100 nm thickness. 2 kV and 500 V steps and/or manual polishing can also be enabled to further reduce thickness, commonly to ~35 nm. This blind, dose-based method tightens the approach to final polishing and shortens manual endpointing time across multiple lamellae. The Osprey FIB Column maintains beam stability across kV changes for predictable material removal. This technique relies on repeating features in the structure, a well-centered feature of interest, or final manual polishing by the user.

## Outcome

Automation optimizes and shortens manual end pointing, focusing operators on expert decision-making. Dose-based pre-thinning produces consistent thickness, while stability across kV transitions and preserved registration reduces endpoint variability.

## Manual polishing

Final polishing can be completed at low kV using incremental milling to reach the target thickness and surface condition. Operators can select SPI for continuous field-free SEM imaging during milling, iSPI for ultra-high-resolution SEM imaging alternating with short milling intervals, and/or FIB Immersion (FIBi) for live ultra-high-resolution SEM within the magnetic field, avoiding mode switches while polishing down to 500 V. The Digital Deflection Electronics provide fine scan rotation step size so mills can be precisely aligned to device features. With optimized low-kV operation, reduced amorphous surface damage is achieved, producing low-damage lamellae suitable for SEM, STEM, and TEM imaging.

## Outcome

Low-kV polishing with live end pointing (SPI, iSPI, FIBi) optimize surface quality with reduced amorphous damage. By shortening and standardizing the final manual step, the workflow improves throughput while maintaining expert-level finishing control.

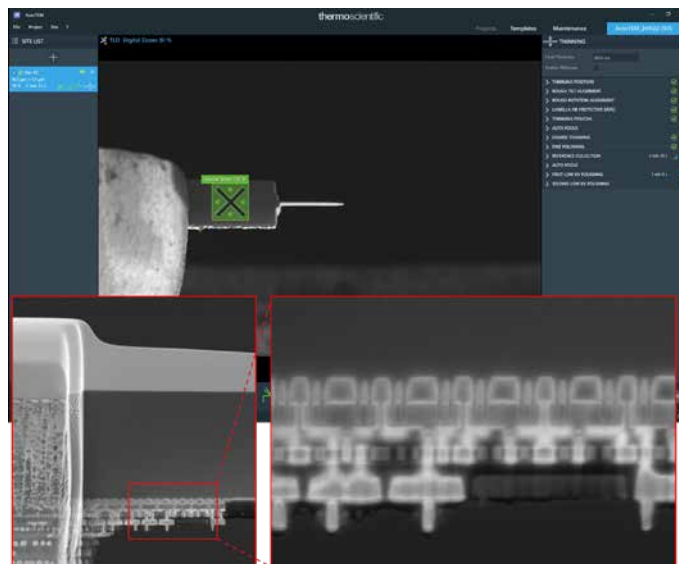


Figure 12. AutoTEM Software blind thinning process and SEM results.

## Summary

### Precision

- High-accuracy stage and digital deflection electronics preserve registration across tilt, rotation, and grid flipping.
- Ion-free SEM deposition protects fragile surfaces prior to FIB exposure.
- Controlled over-tilt, dose-based thinning, and optimized low-kV operation reduce amorphous damage.
- Stable beam performance across kV transitions supports predictable material removal and accurate end pointing.

### Productivity

- AutoTEM 6 Software templates automate project setup through pre-thinning across multiple sites.
- Intelligent site tracking enables site-wise or step-wise execution for flexible batch strategies.
- Geometry-aware trenching and controlled J-cuts minimize redeposition and reduce downstream correction.
- Automated grid management and inverted landing geometry reduce needle consumption and extend usable lift-out cycles.
- Blind thinning shortens manual polishing time and standardizes lamella handoff thickness.

### Robustness

- Automated preventative maintenance and condition-specific alignments maintain consistent beam performance across shifts.
- High-accuracy grid flipping enables rapid reacquisition after in-chamber reorientation.
- Neural network-assisted needle inspection and post selection maintain lift-out consistency.
- Stable MultiChem GIS performance supports uniform deposition across batch runs.

Together, the Helios 6 HD FIB-SEM and AutoTEM 6 Software deliver scalable, high-volume lamella preparation by combining accurate targeting, efficient multi-site execution, and steady long-run stability with reduced operator burden.



Figure 13. Helios 6 HD FIB-SEM.

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