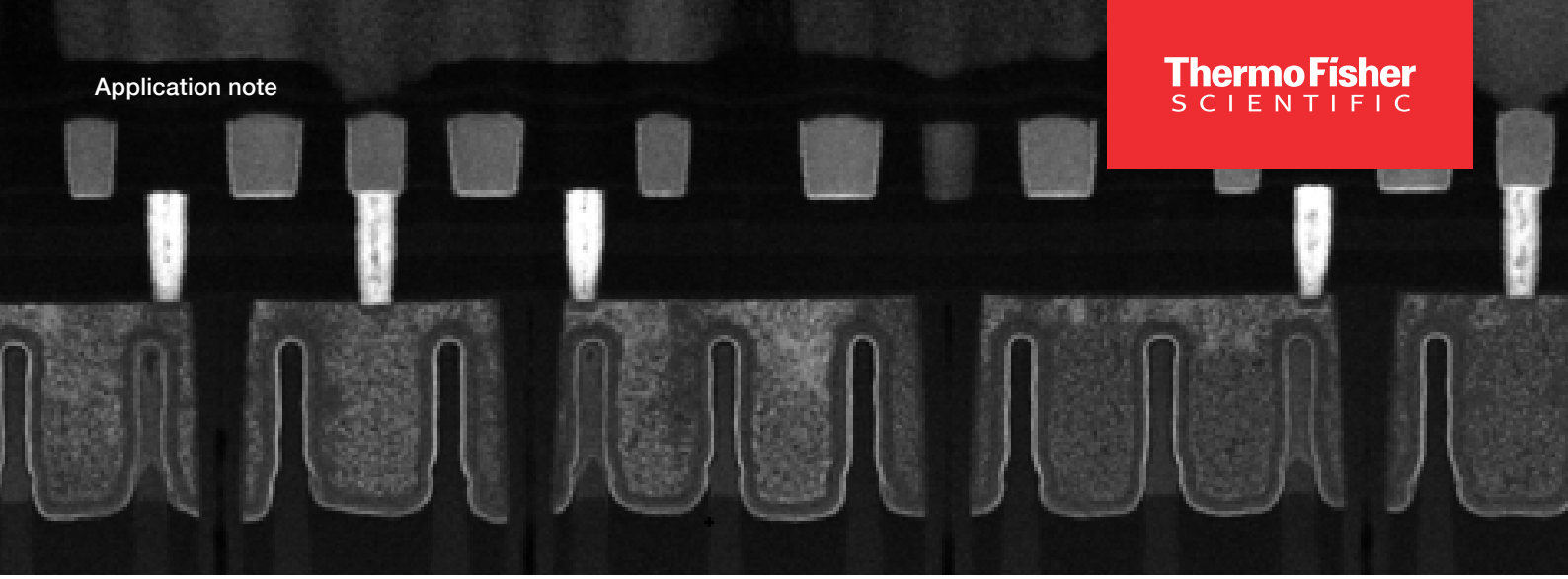
Application note



In situ plasma FIB preparation of structure-targeted TEM lamellae

Introduction

Accurate structural and compositional characterization of semiconductor devices relies on preparation of targeted, high-quality TEM lamellae with focused ion beam milling. Conventional gallium FIB has been widely adopted due to its established automation capabilities and support for high-resolution TEM imaging. The challenge of gallium milling is the tendency of gallium to implant into delicate semiconductor samples, which modifies the chemical composition of specimens.[1]

Plasma focused ion beam (PFIB) milling offers a gallium-free alternative to conventional FIB milling for preparing targeted semiconductor samples with reduced risk of chemical modification. This is particularly important when accurate compositional analysis is needed, as gallium implantation can introduce artifacts and alter local chemistry.[1] Despite these advantages, PFIB has still not been widely adopted for device-scale TEM sample preparation. This is because the broader effective beam profile and associated milling characteristics of plasma ion sources reduce imaging resolution and complicate precise, structure-targeted thinning, particularly at thicknesses below ~20 nm.[2]

This application note showcases a reproducible plasma FIB workflow for *in situ* preparation of ultra-thin (~15 nm) single-device lamellae, with minimal damage, using the Thermo Scientific™ Helios Hydra™ Plasma FIB-SEM.

Key takeaways
Structure-targeted transmission electron microscopy (TEM) of advanced semiconductor devices requires high-quality, electron-thin samples that preserve crystalline structures.
Plasma focused ion beam (PFIB) milling is an alternative to conventional gallium FIB milling for TEM lamella preparation without the chemical modifications caused by gallium implantation, supporting more accurate compositional analysis.
This application note presents a fully *in situ* multi-ion plasma FIB workflow for preparing ~15 nm thick TEM lamellae from 5 nm node FinFET devices.
Broadly, this approach supports reproducible ultra-thin (<20 nm), single-device-targeted sample preparation that avoids sample transfer between multiple instruments as well as the complications associated with conventional gallium FIB.

Experimental methods

TEM lamellae were prepared using the Helios Hydra PFIB-SEM, which is equipped with a switchable plasma ion source that can alternate between xenon and argon ions. A commercially available 5 nm process-node FinFET device containing nanoscale features was used as the target sample. Lamellae were prepared using a standard inverted lift-out workflow and were thinned to contain a single FinFET device (Figure 1). Final thinning conditions were optimized for precise endpointing and uniform thickness across single-device regions (Table 1).

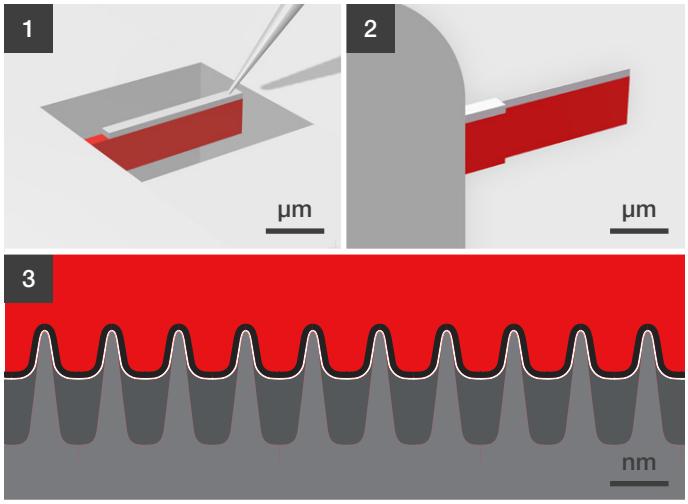


Figure 1. Workflow schematic of the lamella preparation process. (1) Chunk and sample lift out. (2) 30 kV xenon coarse thinning. (3) 5 kV xenon, 1 kV xenon, and 500 V argon polishing and final endpointing on a single gate structure.

Thinning step	Voltage	Ion species	Beam current	Stage tilt
Coarse thinning	30 kV	Xe	100 and 300 pA	56.5°
Intermediate polish	5 kV	Xe	100 pA	58°
Fine polish	1 kV	Xe	100 pA	59°
Final clean	500 V	Ar	100 pA	60°

Table 1. Process workflow conditions for *in situ* multi-ion PFIB preparation of ultra-thin structure-targeted TEM lamellae. Incremental reduction in milling voltage lowers the risk of ion-induced damage and improves final surface quality by maintaining controlled material removal.

An inverted preparation geometry was used to reduce curtaining artifacts during thinning and to place the region of interest near the bottom of the inverted lamella. This accommodates aggressive overtilt conditions to create a wedge-shaped structure in which the upper portion of the lamella was thicker than the lower device region. This geometry improves lamella stability during thinning steps and reduces the sample's susceptibility to bending or warping (Figure 2).

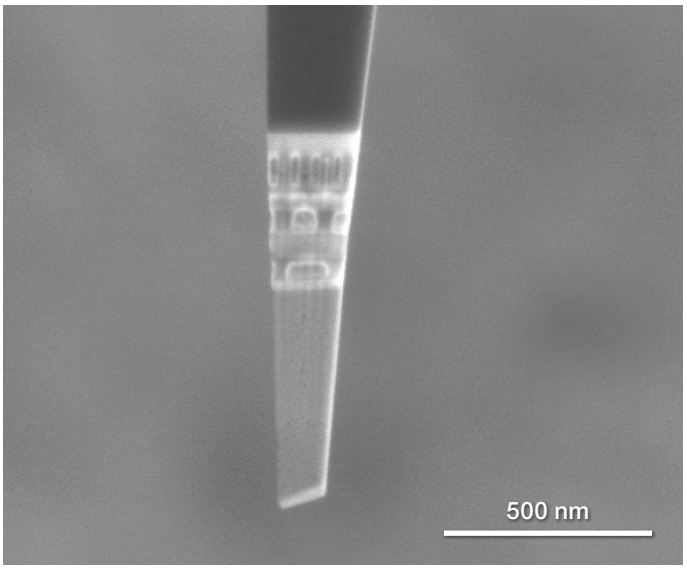


Figure 2. Lamella end-on view obtained during 30 kV coarse thinning, showing the inverted wedge geometry.

Endpoint monitoring was performed using iSPI functionality, which acquires SEM images after each milling slice (or defined time interval) to provide feedback. This offers real-time observation of the targeted device region during thinning and facilitates precise endpointing of the final lamella structure.

One of the most critical parts of the thinning process is maintaining precise milling alignment relative to the device structures of interest. Here, small scan rotations were applied to the FIB to correct for minor skew so that milling occurred normal to the device geometry. These fractional adjustments are particularly important during final thinning, where even slight misalignment could result in non-uniform thickness across the lamella.

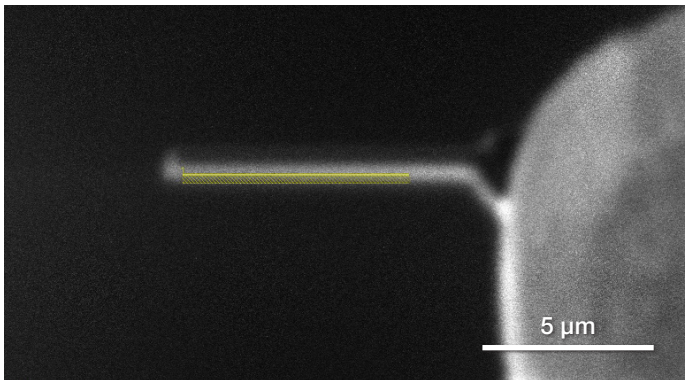


Figure 3. 5 kV intermediate polish step shown with 6.5 µm-wide milling pattern (yellow).

A wide thinning window (~6 µm) produces large, electron-transparent regions suitable for TEM analysis. Achieving uniform thinning across such a wide region requires near-perfect beam deskew and well-aligned beam conditions throughout the thinning process. Existing gallium-FIB-based workflows have used external low-energy broad-beam or NanoMill processing along with further thinning to reduce surface amorphization and improve final specimen quality.[3,4] The Helios Hydra PFIB-SEM, meanwhile, can perform xenon thinning and low-energy argon polishing fully *in situ*, removing the need for sample transfer.

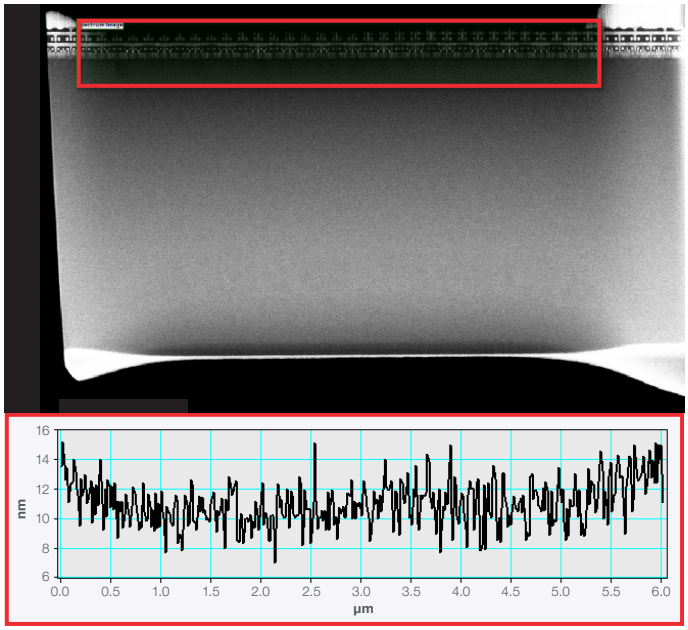


Figure 4. STEM-EELS image verifying that the sample lamella has a ~12 nm thickness across the wide (~6 µm) area.

Results and discussion

The Helios Hydra PFIB-SEM is able to successfully prepare ~15-nm-thick TEM lamellae targeted to individual 5 nm node FinFET devices. With this approach, large-area uniformity is maintained across the device region. Thickness was quantified using STEM-EELS analysis, confirming a thickness range of 8 to 15 nm and indicating precise endpoint control during final polishing steps (Figure 4).

High-resolution HAADF-STEM imaging showed that the crystalline lattice structure was maintained throughout the thinned region, with minimal structural damage during final thinning (Figure 5). The atomic lattice can be clearly resolved, indicating that the sample is suitable for atomic-scale structural analysis. This shows that PFIB thinning preserves crystalline structure, minimizes damage, and avoids gallium implantation.

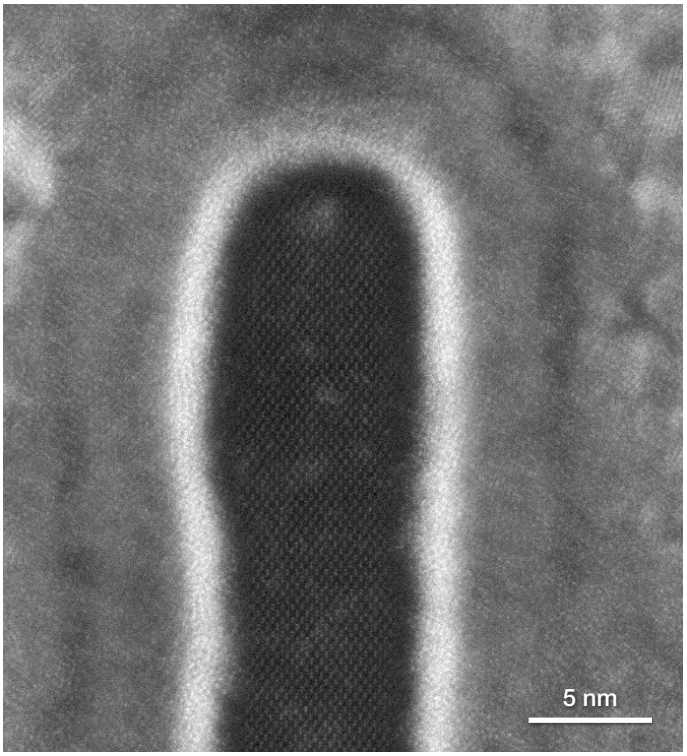


Figure 5. HAADF-STEM image of FinFET channel crystallinity.

These results were reproducible across multiple lamellae preparations, demonstrating that sub-20-nm, device-targeted lamellae can be reliably achieved with plasma FIB. Compared to conventional gallium FIB workflows, which typically need about two hours for similar TEM lamella preparations, the Helios Hydra PFIB-SEM required about two and a half hours for fully *in situ* bulk milling, xenon thinning, and low-energy argon polishing. These results demonstrate the practicality of integrated multi-ion PFIB processing for advanced-node TEM sample preparation, which eliminates gallium implantation and avoids the need for external post-processing workflows.

References

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Notes

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