Ultra-high spatial resolution EDS mapping of semiconducting materials with FEG-SEM

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Outline

01 EDS detector details

02 Sample details: Bulk vs e-transp.

03 Application examples – Bulk

04 Application examples – e-transparent

05 Ultra high-resolution EDS maps in SEM?

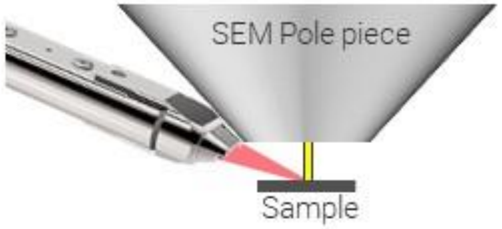
06 Summary

Bruker XFlash® EDS detectors
Conventional EDS vs. Oval 100mm^2 vs. FlatQUAD

	XFlash® 730/760/7100	XFlash® Oval 100mm^2	XFlash® FlatQUAD EDS
			
SDD geometry			
HV	up to 30 kV	up to 30 kV	up to 20 kV (max 30 kV)
WD (min)	~ 4 mm	~ 2 mm	~ 8 mm
Window	optional	windowless	multiple
Solid angle (up to)	0.1 sr	0.4 sr	1.1 sr

Bruker XFlash® Oval 100mm^2 windowless EDS
Features and advantages

XFlash ® Oval 100mm^2

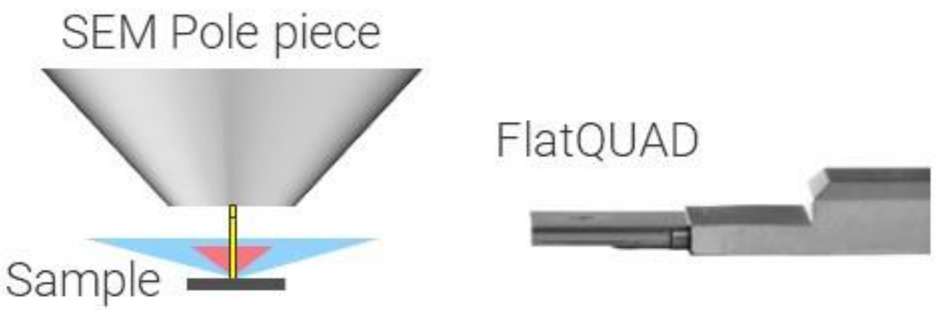


- Oval shaped SDD chip geometry
- High solid angle of 0.4 sr
- High collection efficiency
- High take-off angle of 35˚

- Ultra-high spatial resolution – high sensitivity
- Excellent spectral quality at low and high kV
- Light element, low kV - low probe current analysis
- TEM-like EDS measurements in SEM
- Fast data processing (up to 600,000 cps output count rate)

Bruker XFlash® FlatQUAD EDS
Features and advantages

XFlash ® FlatQUAD



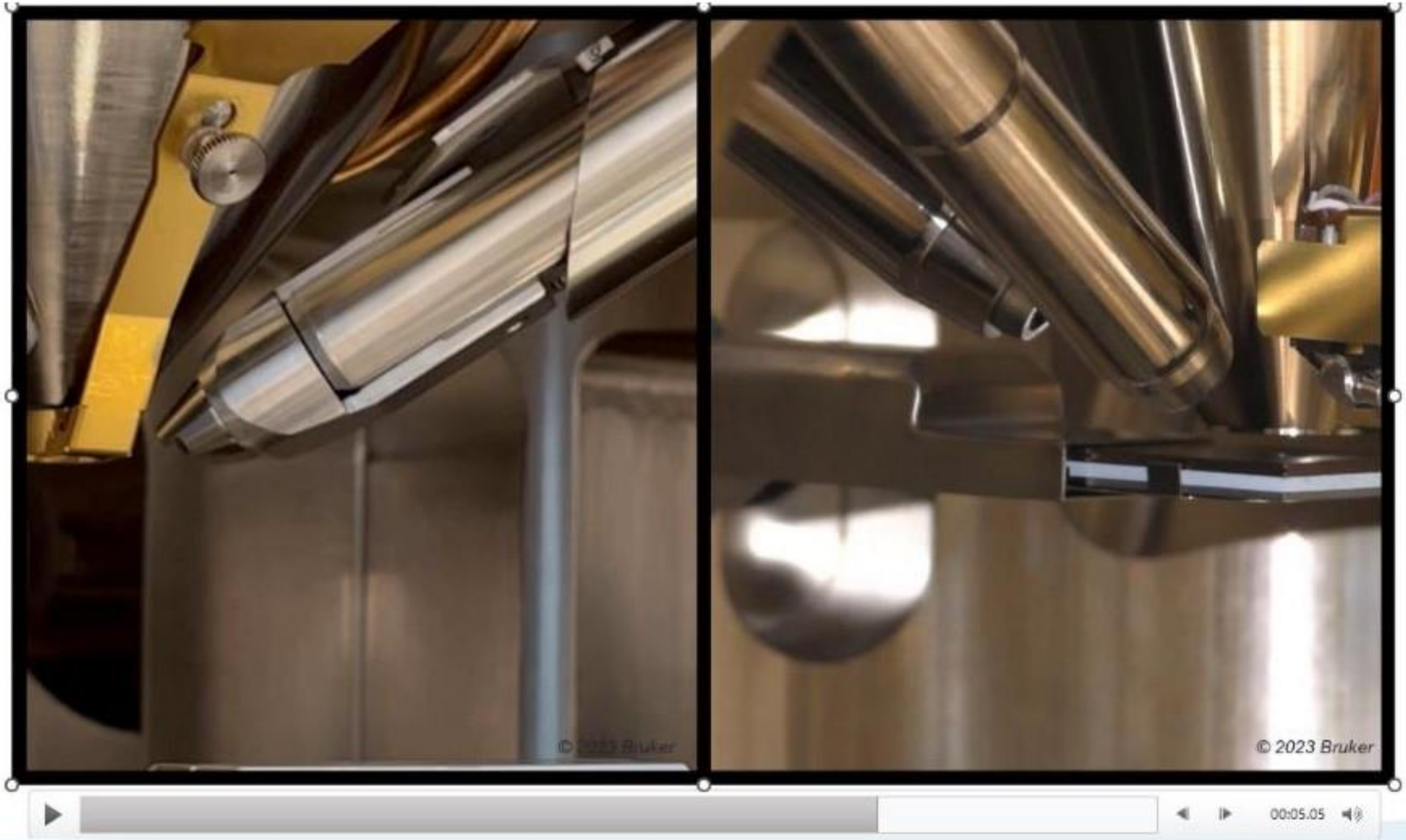
- Annular 4-segment (4x) SDD geometry, central ap.
- Side entry EDS (STEM/BSE like)
- Large solid angle of 1.1 sr
- High take-off angle (~60˚)
- Optimal signal collection geometry

- High sensitivity at very low probe currents ~few pA
- Minimize sample charging/damage/C-deposition at low PC
- High vacuum conditions EDS – high resolution
- Low vacuum capability
- Moderate probe currents for high-speed EDS mapping
- Low x-ray yield samples: Low PC – High resolution
- Nanoparticles, Thin lamellae, beam sensitive materials

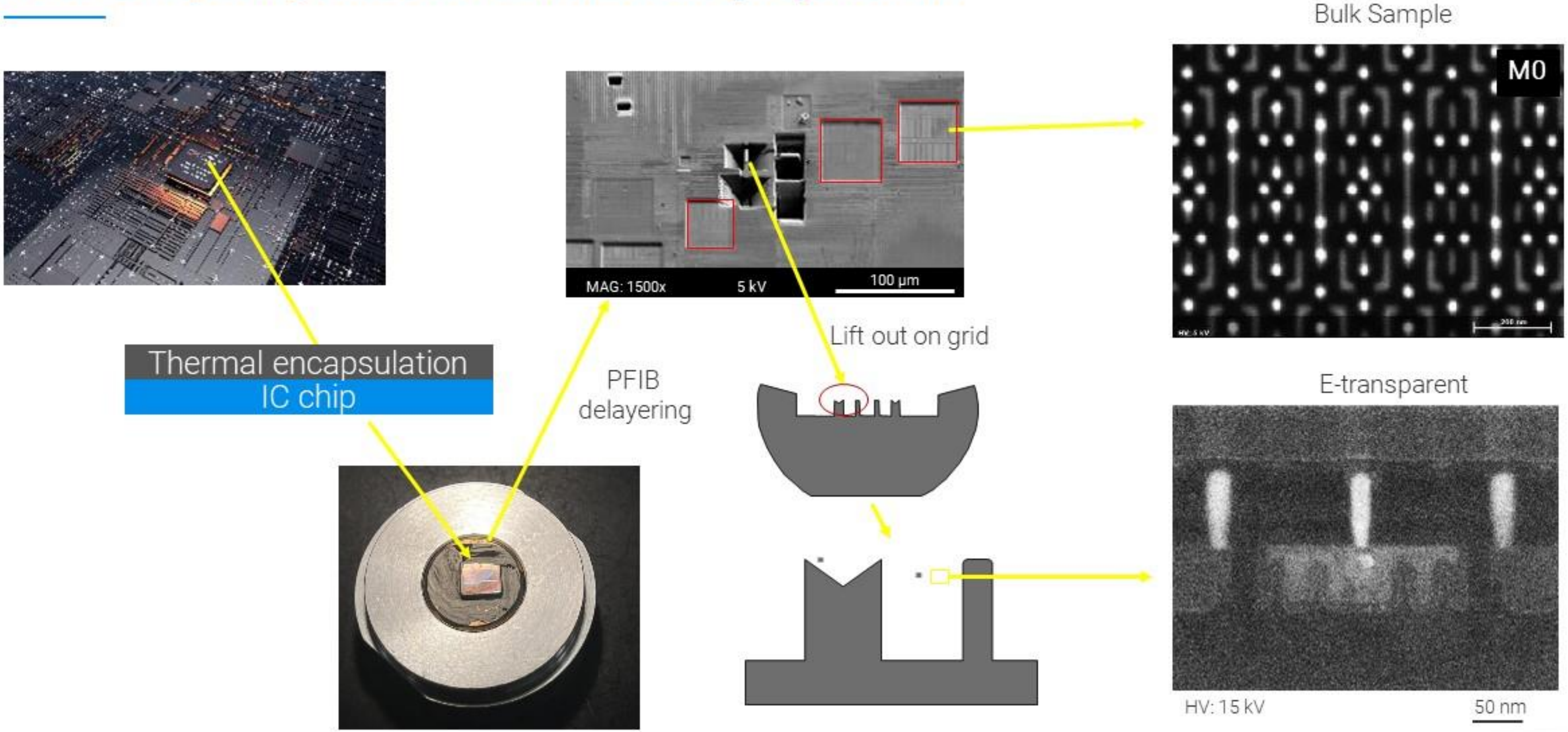
Bruker XFlash® FlatQUAD EDS
Insertion of EDS detectors: Video

100 mm²

Slide with video: Please watch the free on-demand version.

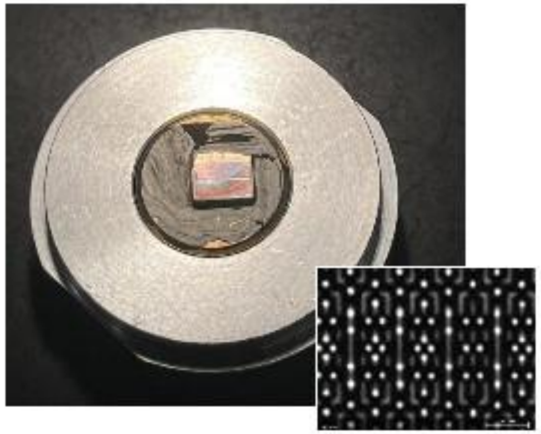


Sample preparation
PFIB delayering and FIB/TEM lamella preparation

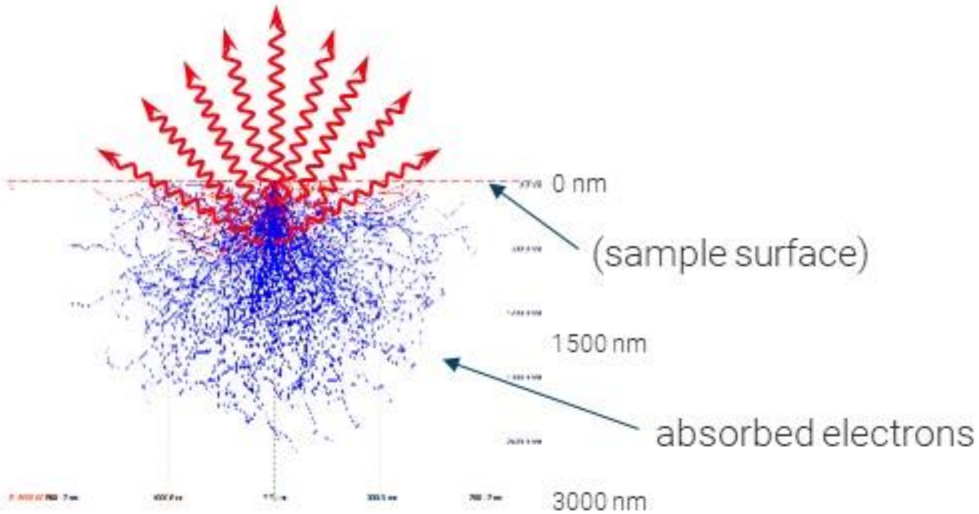


Sample preparation
Bulk vs e-transparent sample

Bulk Sample

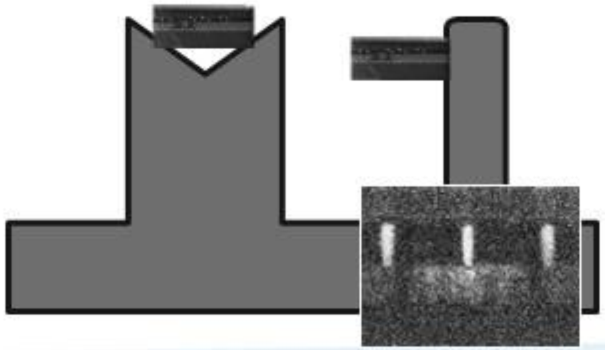


Bulk specimen

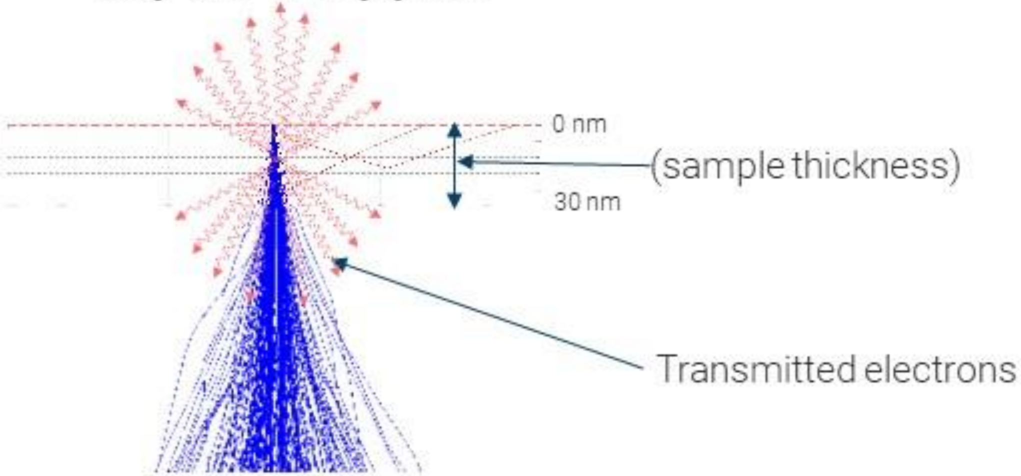


Very low X-ray yield

E-transparent



E-transparent
FIB/TEM lamellae

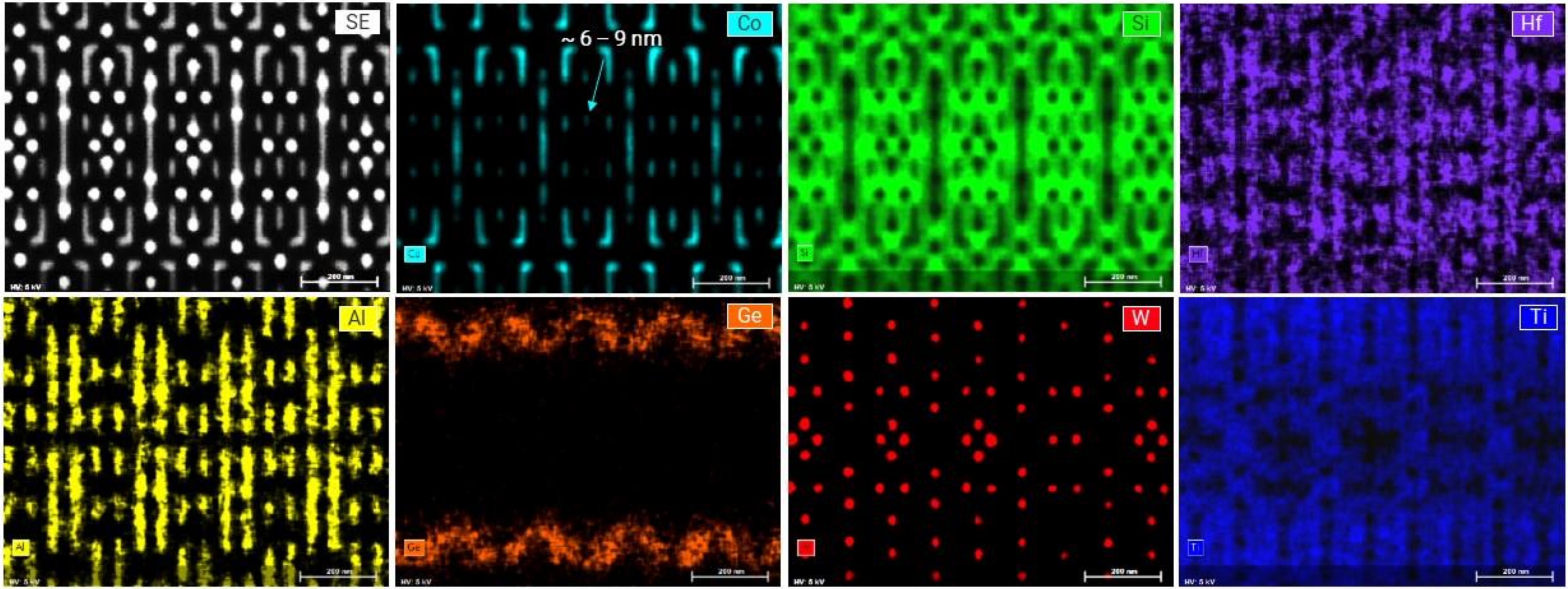


7 nm node FinFET – M0 layer

100 mm²

Bulk sample / XFlash® Oval 100mm² windowless EDS

SEM HV / Probe current / Aq. time / Output count rate (OCR)
5 kV / 1.1 nA PC / 600s / OCR 31,300 cps



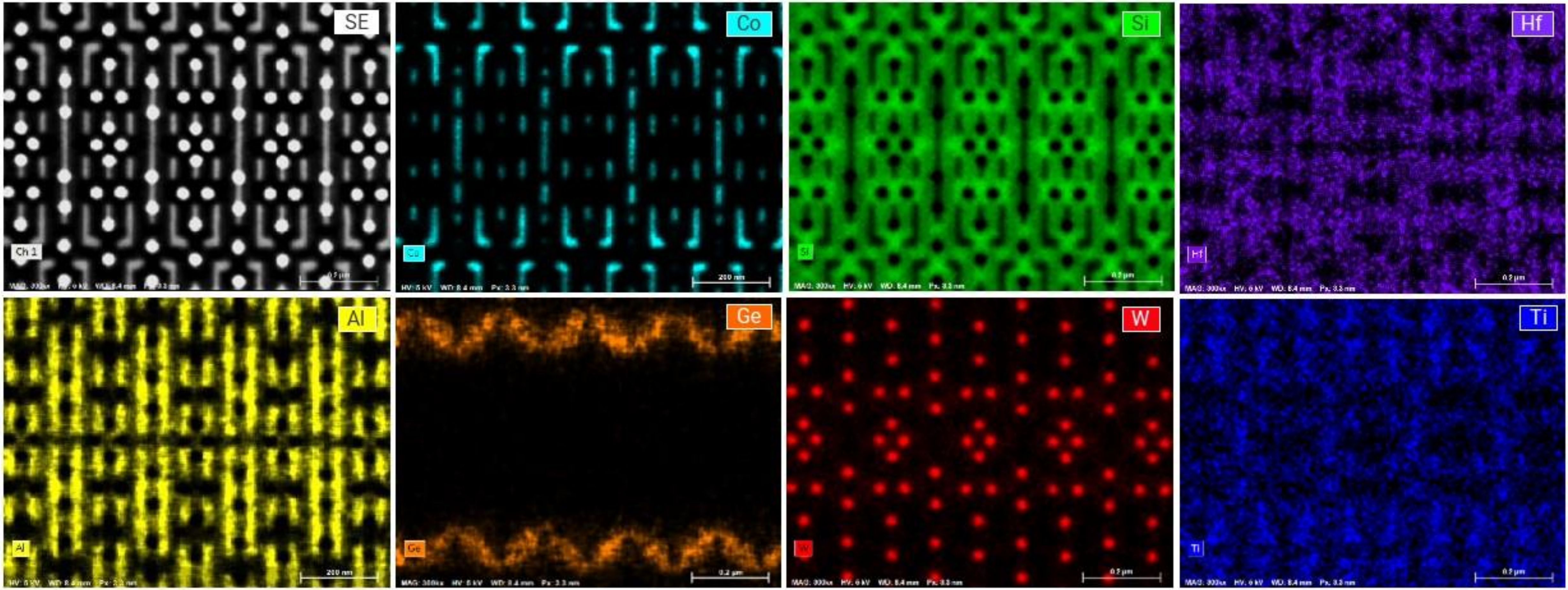
HV: 5 kV FOV: 910 x 630 nm

200 nm

200 nm

7 nm node FinFET – M0 layer
Bulk sample / XFlash® FlatQUAD EDS

SEM HV / Probe current / Aq. time / Output count rate (OCR)
5 kV / 1.1 nA PC / 120s / OCR 309,000 cps



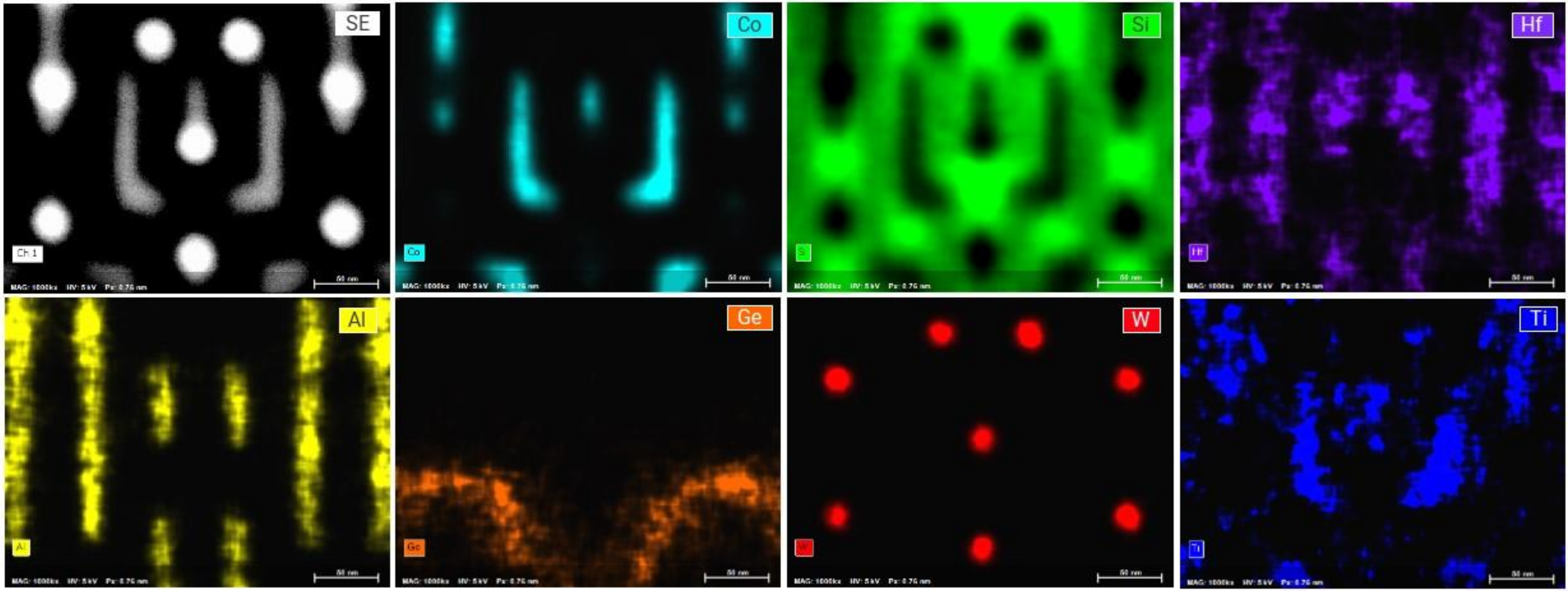
HV: 5 kV   FOV: 900 x 675 nm

200 nm

7 nm node FinFET – M0 layer
Bulk sample / XFlash® Oval 100mm² windowless EDS

100 mm²

SEM HV / Probe current / Aq. time / Output count rate (OCR)
5 kV / 1.1 nA PC / 355s / OCR 31,300 cps

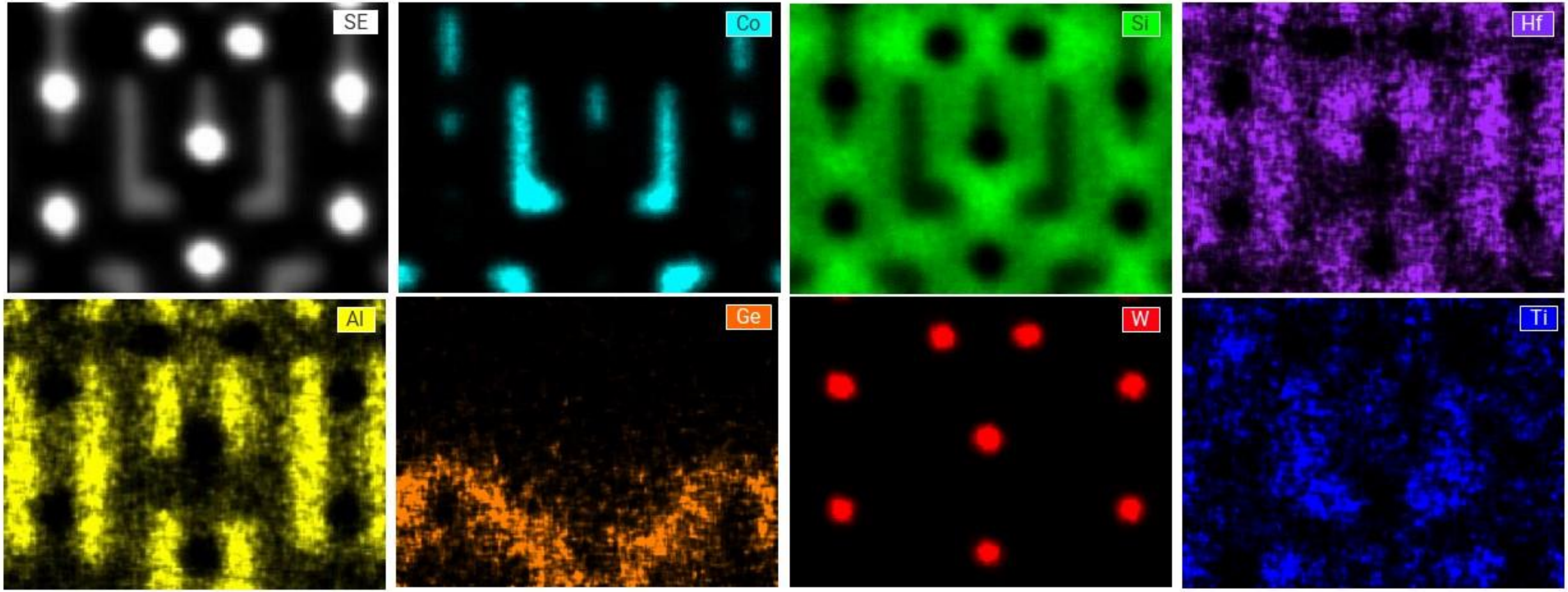


HV: 5 kV FOV: 280 x 210 nm

50 nm

7 nm node FinFET – M0 layer
Bulk sample / XFlash® FlatQUAD EDS

SEM HV / Probe current / Aq. time / Output count rate (OCR)
5 kV / 1.1 nA PC / 89s / OCR 305,300 cps



HV: 5 kV FOV: 250 x 188 nm

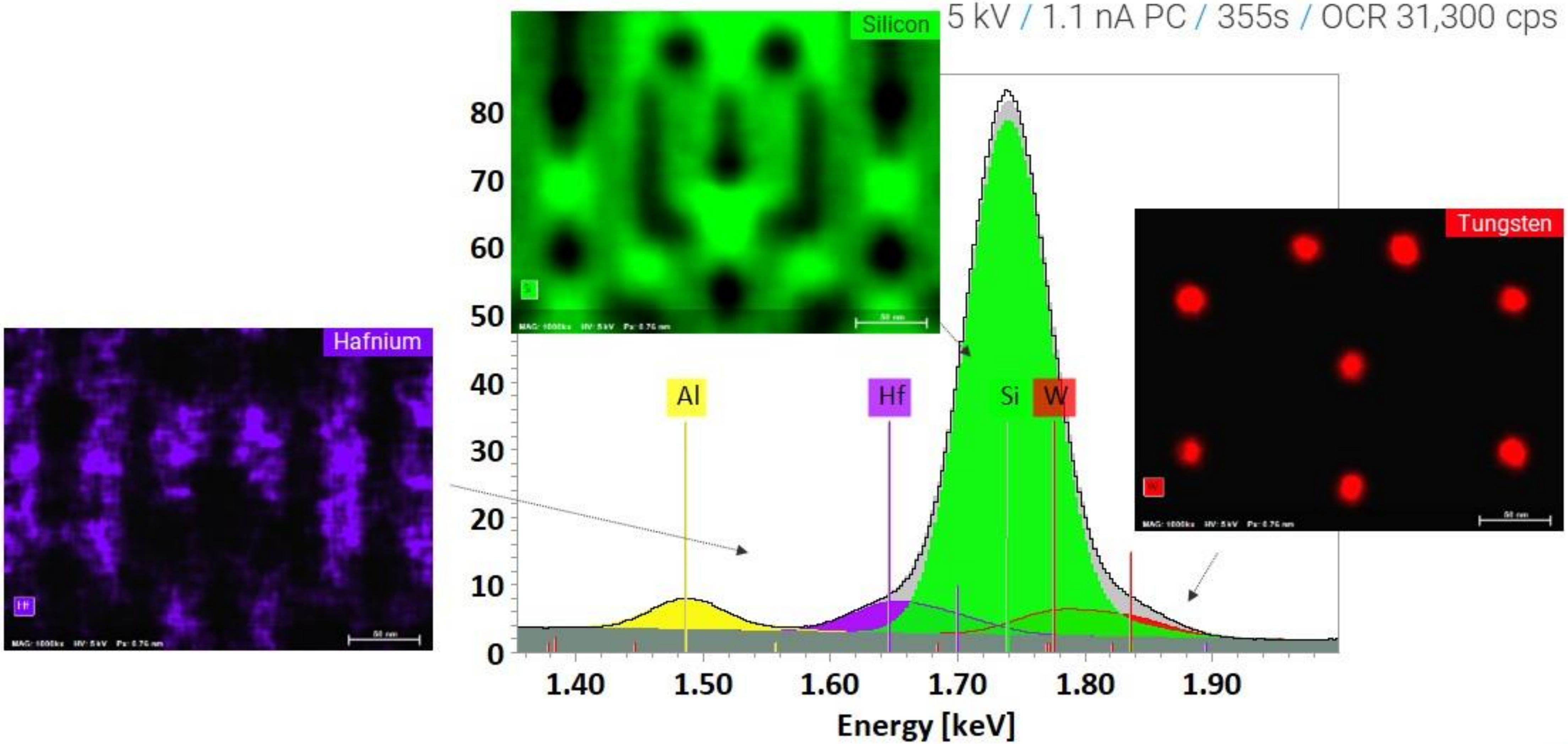
50 nm

7 nm node FinFET – M0 layer

Bulk sample / XFlash® Oval 100mm² windowless EDS

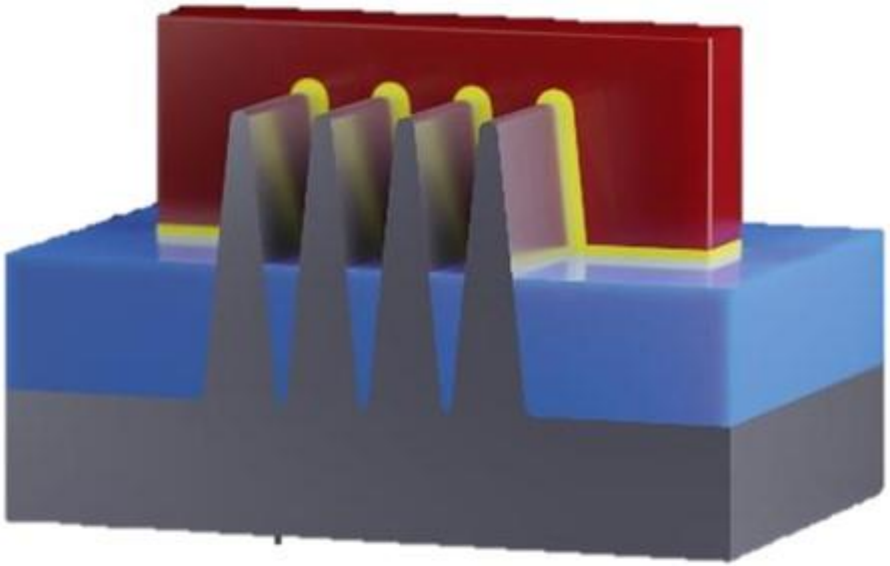
100 mm²

5 kV / 1.1 nA PC / 355s / OCR 31,300 cps

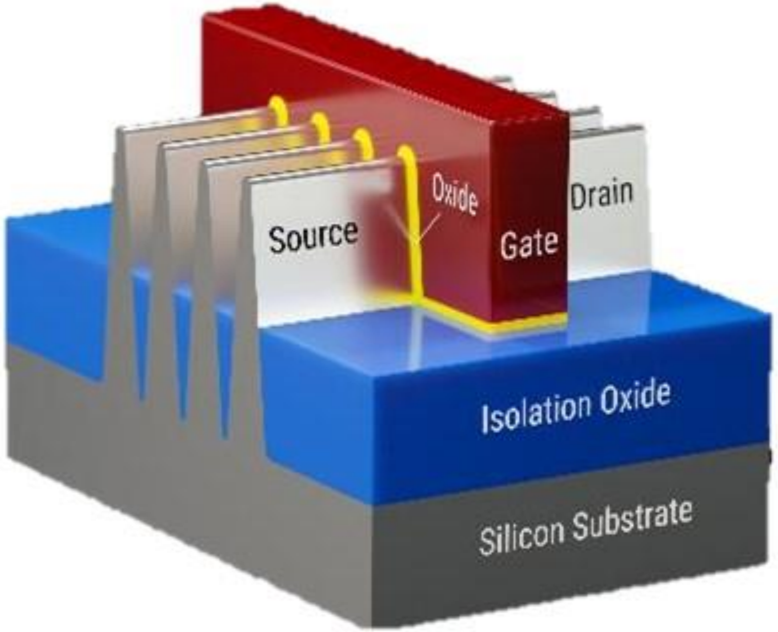


14 nm node FinFET – FIB lamella ~ 30 nm
E-transparent specimen

Fin cut



Gate cut



14 nm node FinFET – Fin cut lamella ~ 30 nm

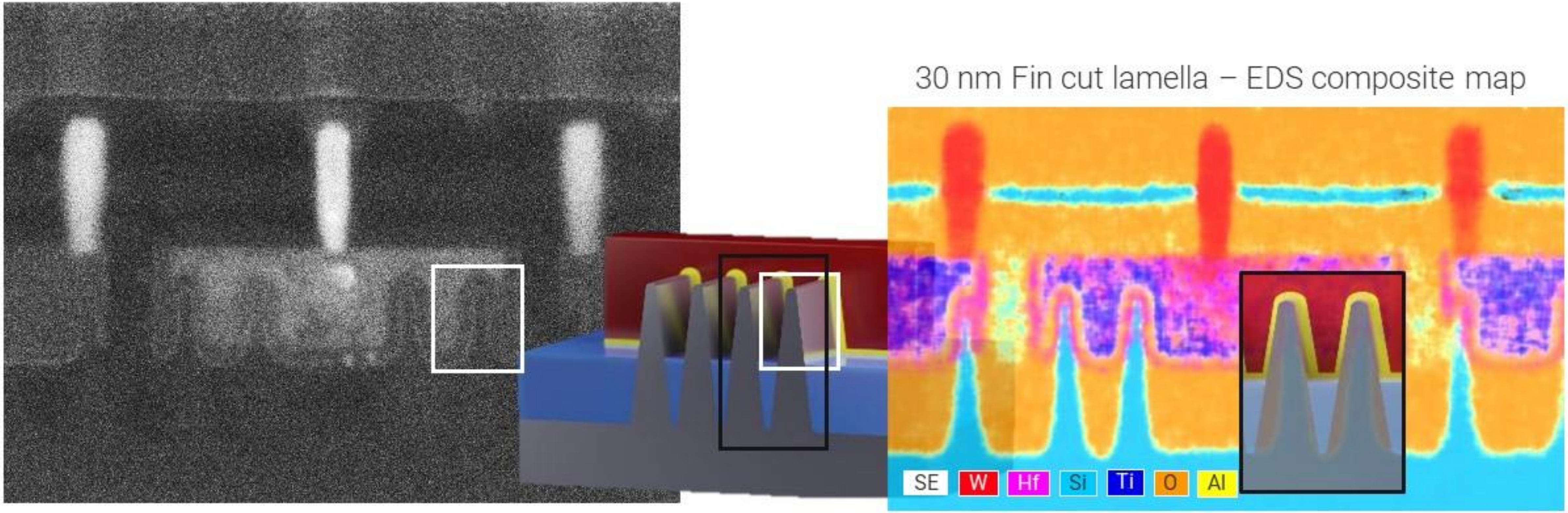
E-transparent specimen 1 (Fin cut)

100 mm²

15 kV / 321 pA PC / 1500s / OCR 12,000 cps

30 nm Fin cut lamella – SEM image

30 nm Fin cut lamella – EDS composite map



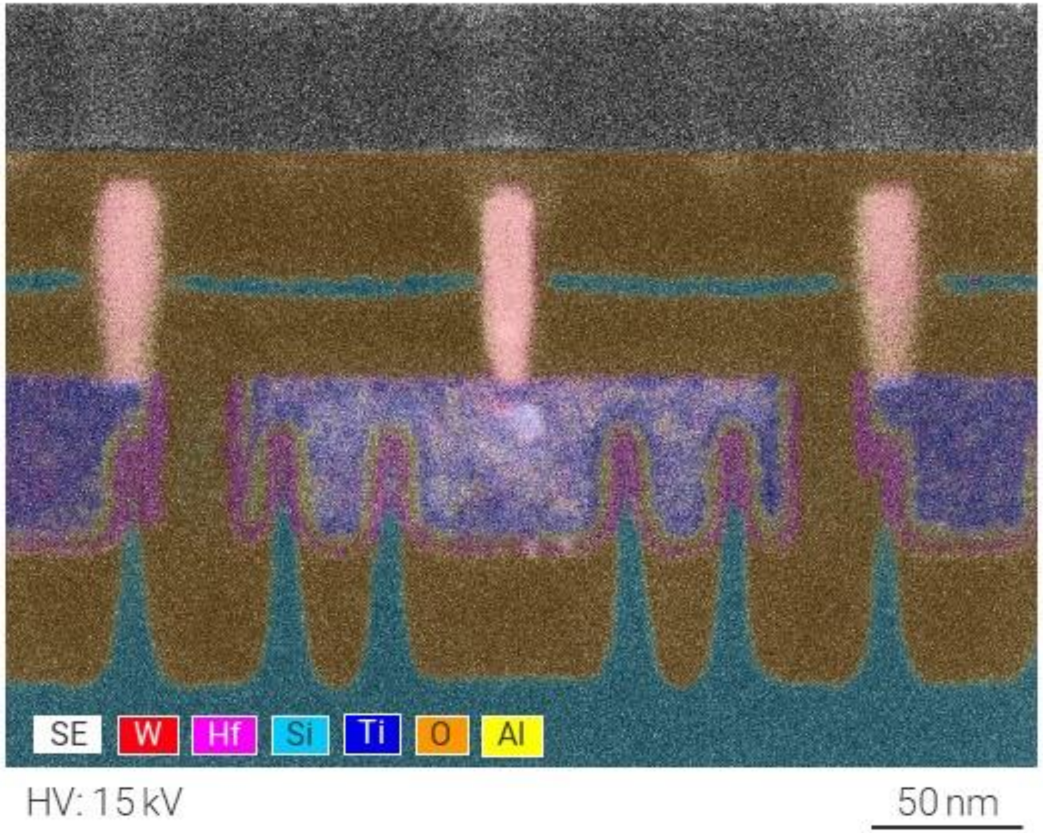
HV: 15 kV 50 nm

HV: 15 kV 100 nm

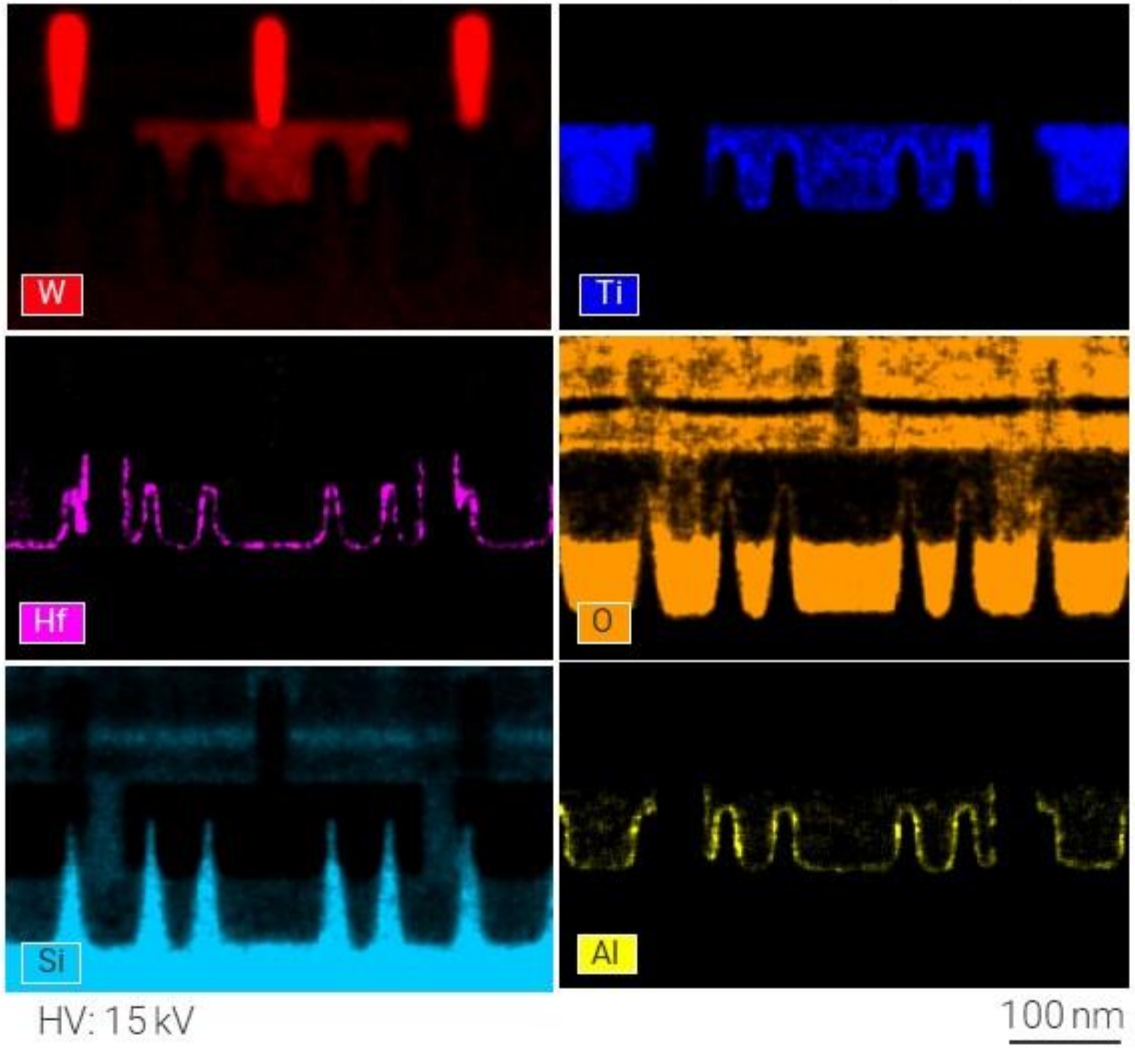
14 nm node FinFET – Fin cut lamella ~ 30 nm

E-transparent specimen 1 (Fin cut)

Fin cut lamella



15 kV / 321 pA PC / 1500s / OCR 12,000 cps

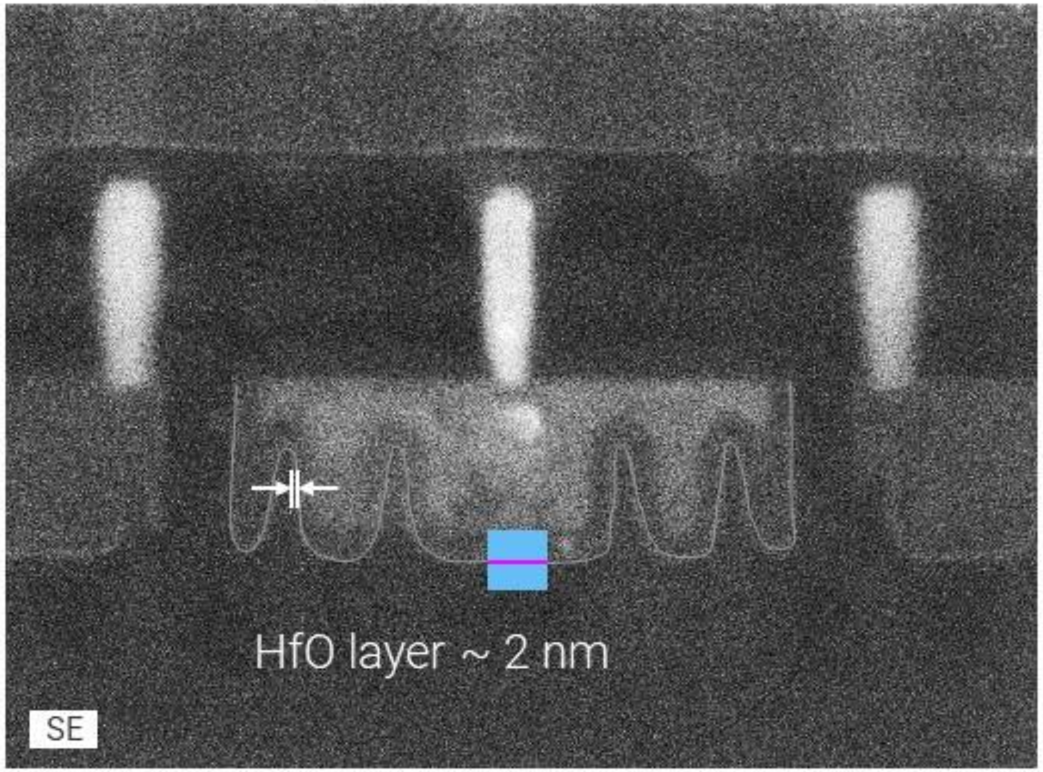


14 nm node FinFET – Fin cut lamella ~ 30 nm
Imaging vs EDS spatial resolution

100 mm²

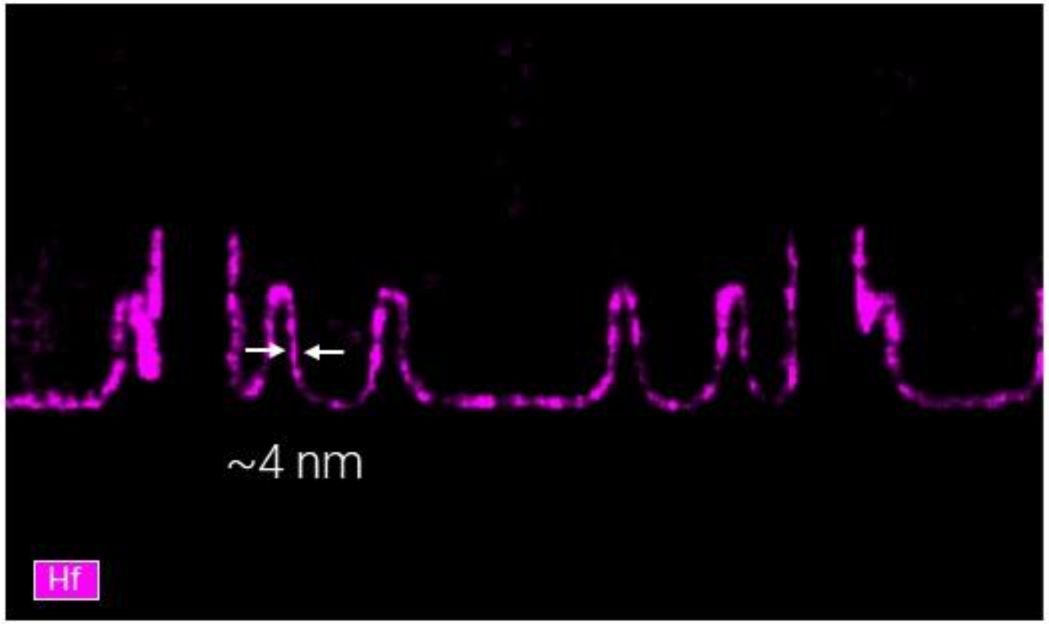
15 kV / 321 pA PC / 1500s / OCR 12,000 cps

Imaging spatial resolution



HV: 15 kV   50 nm

EDS spatial resolution

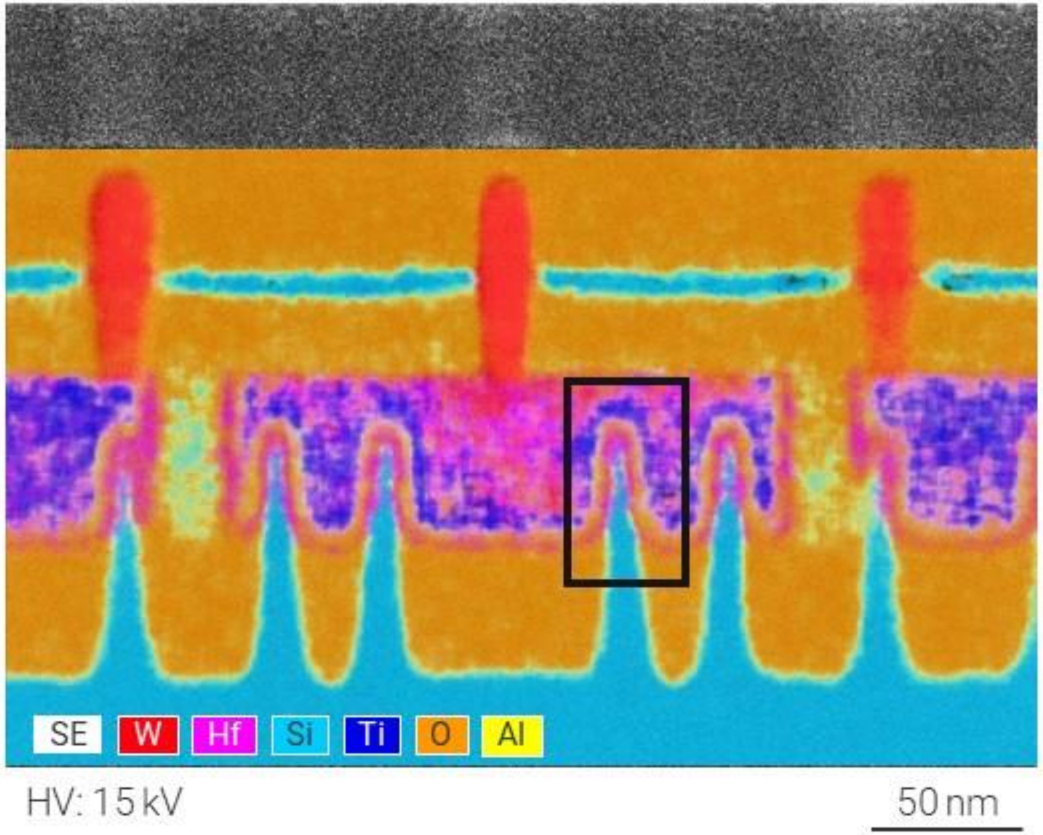


HV: 15 kV   50 nm

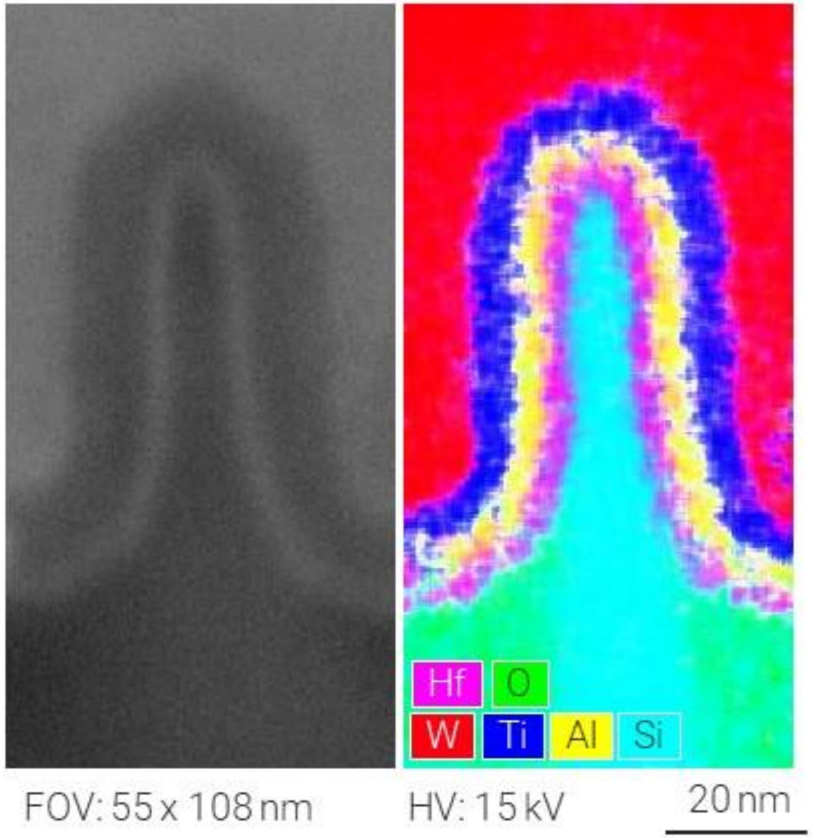
14 nm node FinFET – Fin cut lamella ~ 30 nm
High resolution to Ultra high resolution

100 mm²

Fin cut lamella



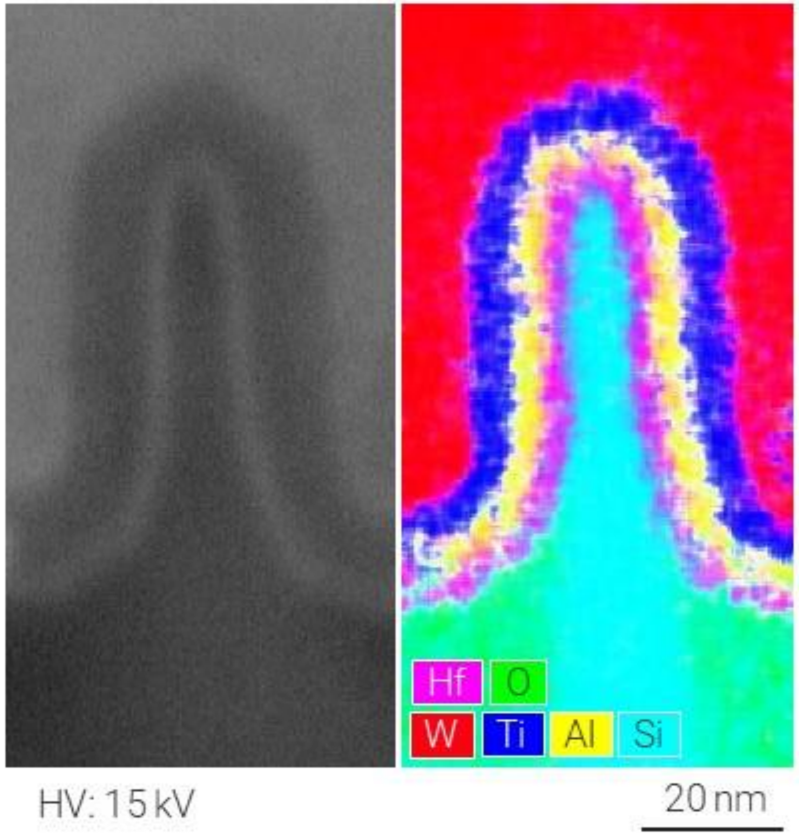
15 kV / 321 pA PC / 570s / OCR 14,400 cps

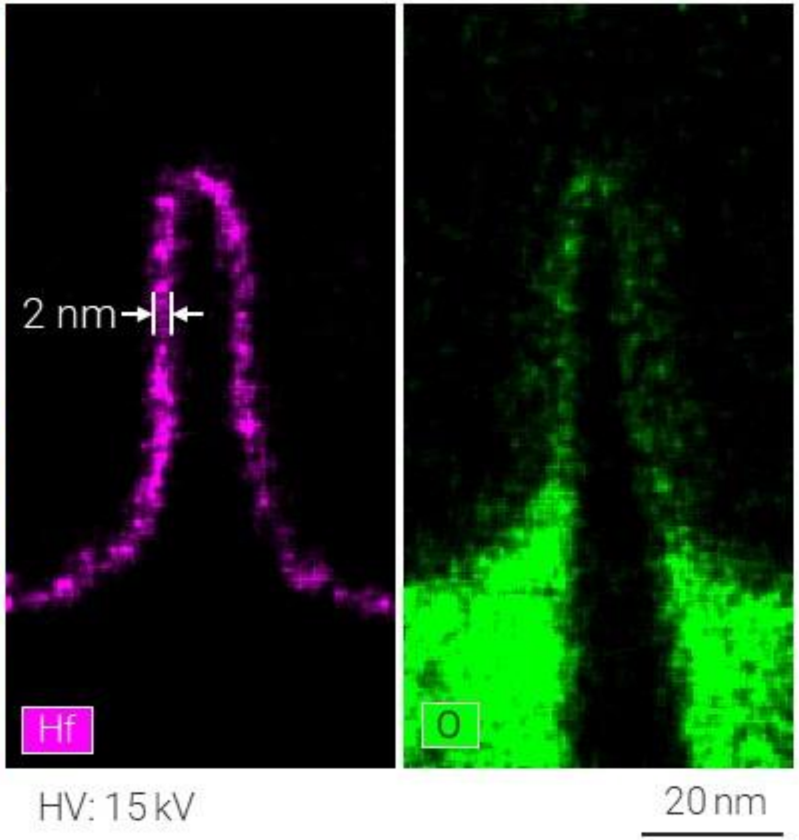


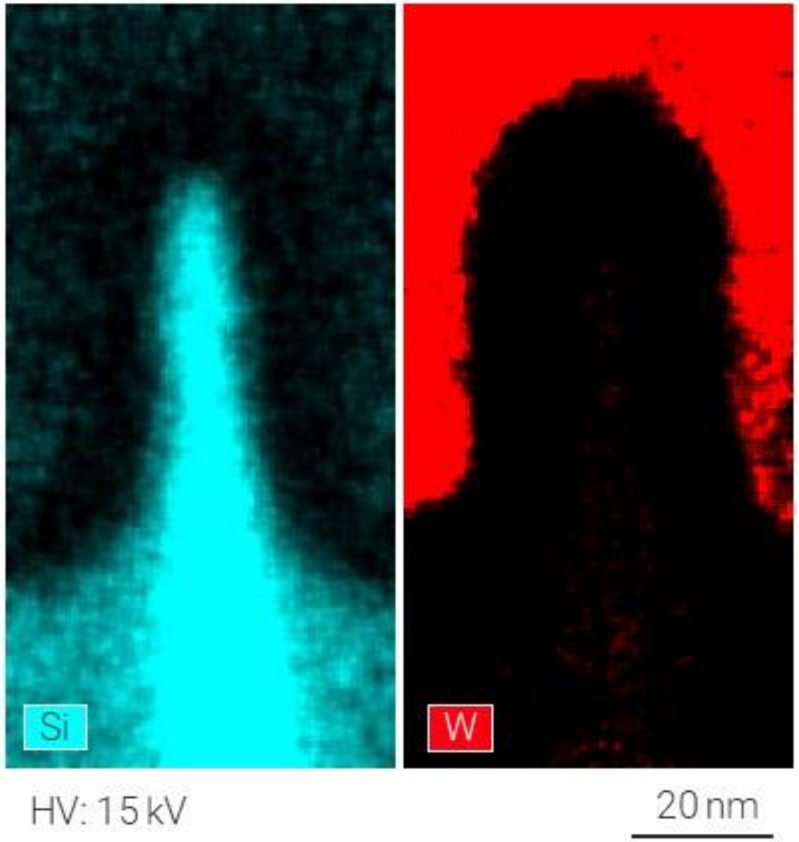
14 nm node FinFET – Fin cut lamella ~ 30 nm
Ultra-high spatial resolution chemical mapping

100 mm²

15 kV / 321 pA PC / 570s / OCR 14,400 cps

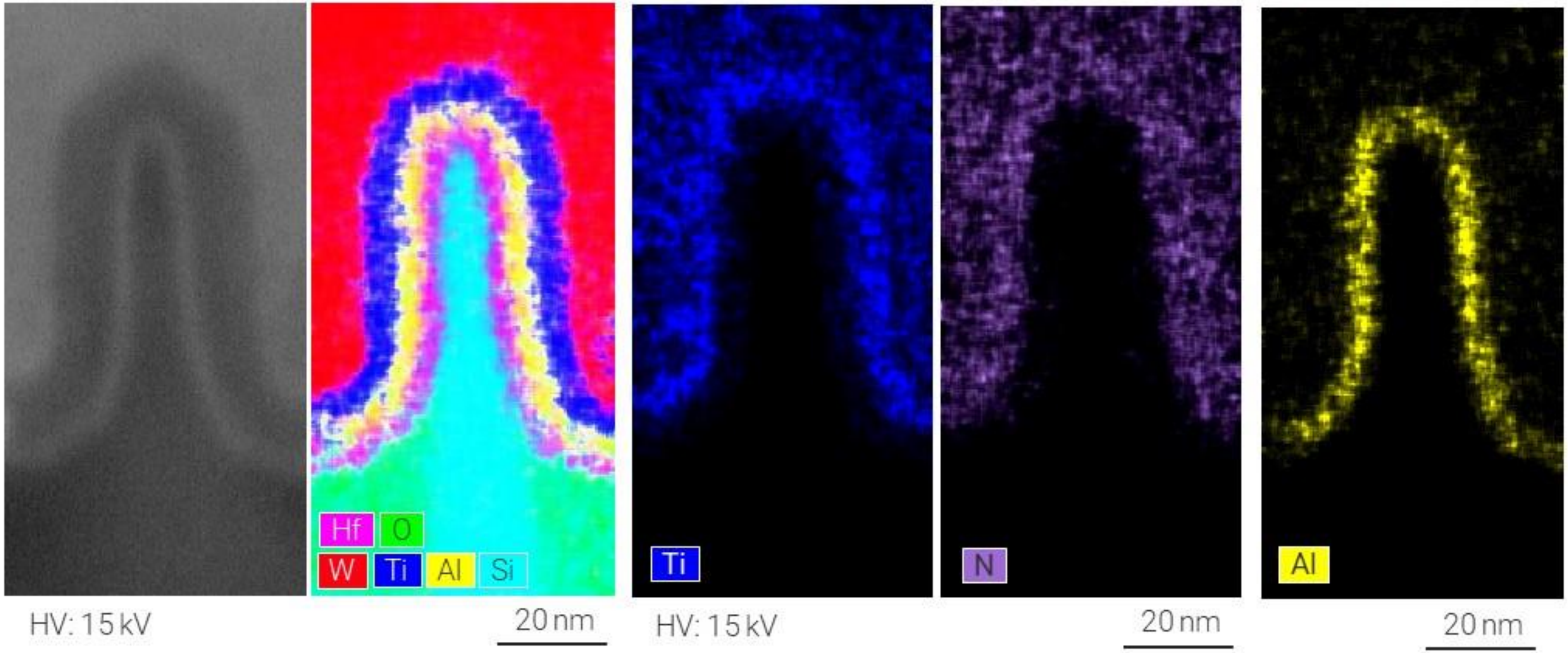






14 nm node FinFET – Fin cut lamella ~ 30 nm
Ultra-high spatial resolution chemical mapping

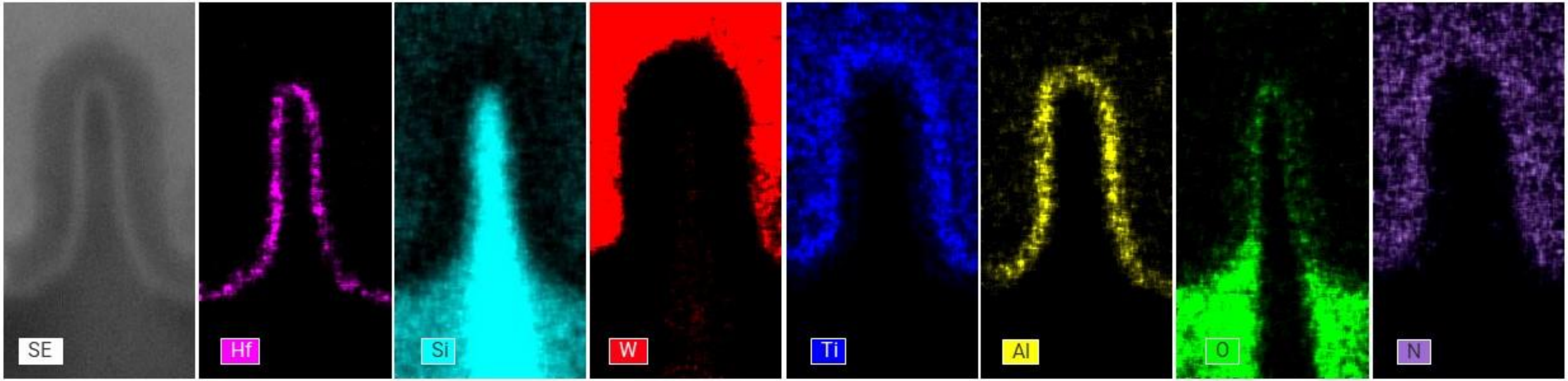
15 kV / 321 pA PC / 570s / OCR 14,400 cps



14 nm node FinFET – Fin cut lamella ~ 30 nm
Individual elemental maps

100 mm²

15 kV / 321 pA PC / 570s / OCR 14,400 cps

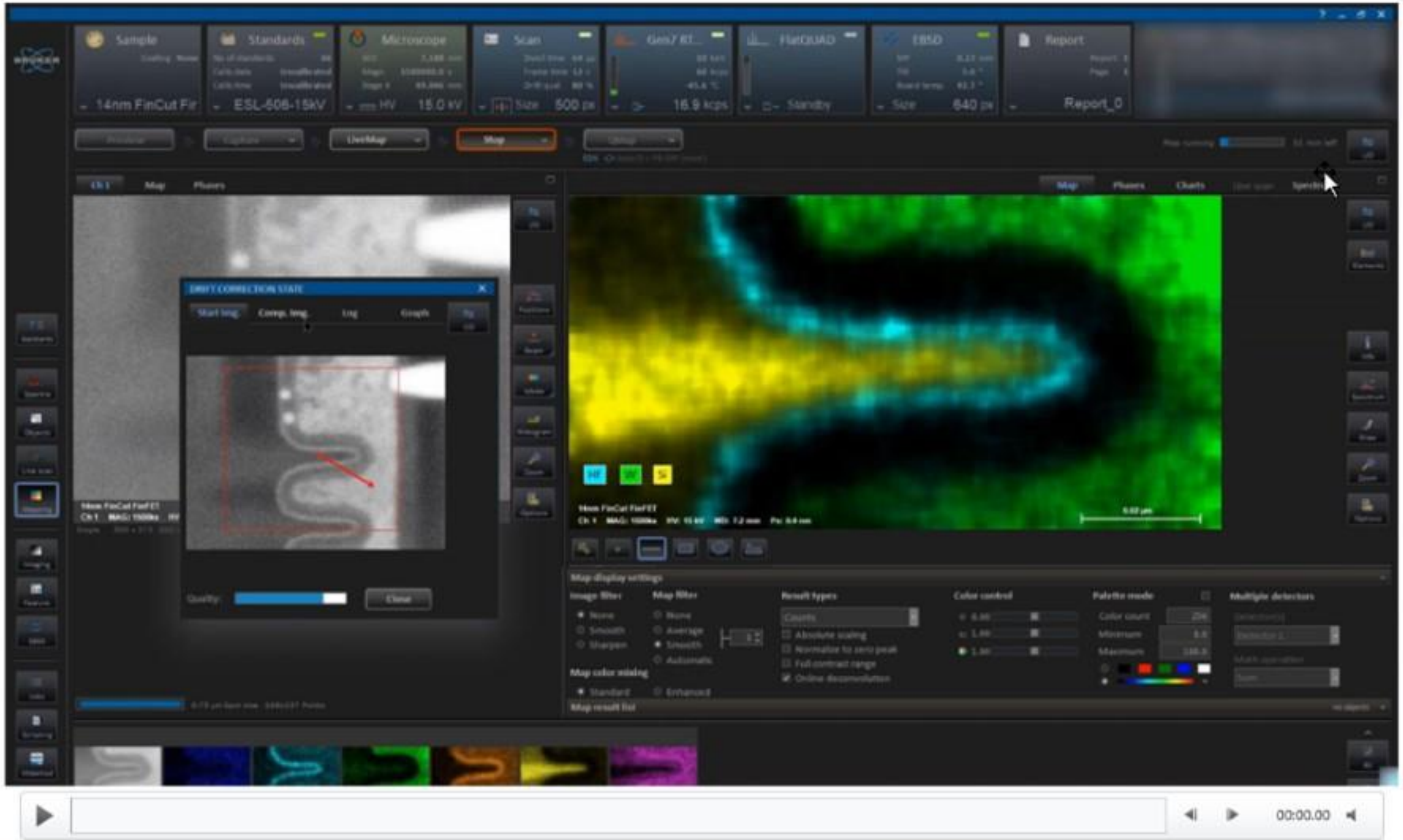


FOV: 55 x 108 nm SEM HV: 15 kV 20 nm

14 nm node FinFET – Fin cut lamella ~ 30 nm
Live acquisition video: Drift correction at high magnification

100 mm²

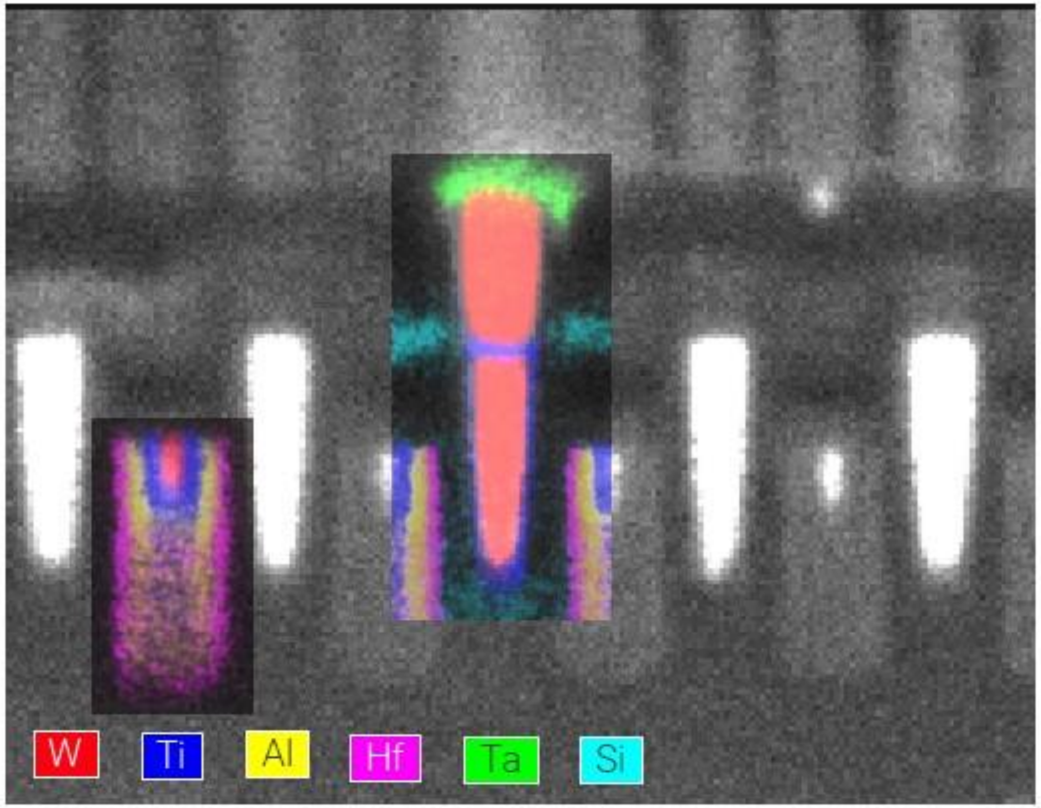
Slide with video: Please watch the free on-demand version.



14 nm node FinFET – Gate cut lamella ~ 30 nm
E-transparent specimen 2 (Gate cut)

100 mm²

Gate cut structure

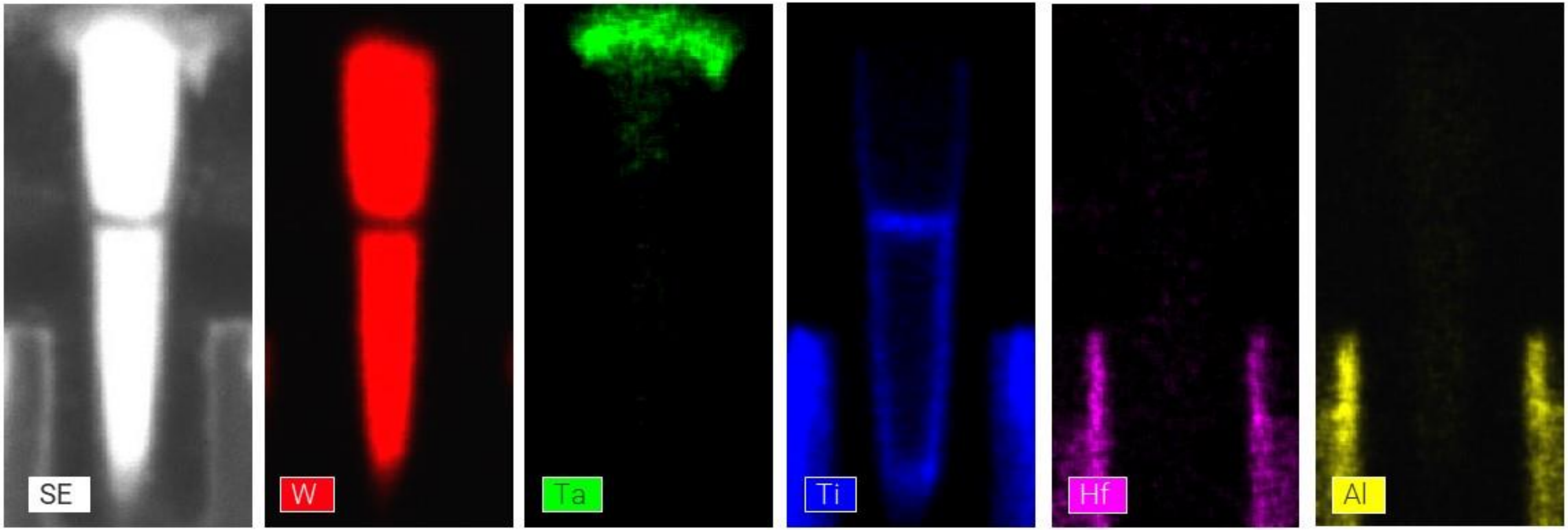


HV: 15 kV

100 nm

14 nm node FinFET – Gate cut lamella ~ 30 nm
Chemical mapping of complex structures at UHR

100 mm²



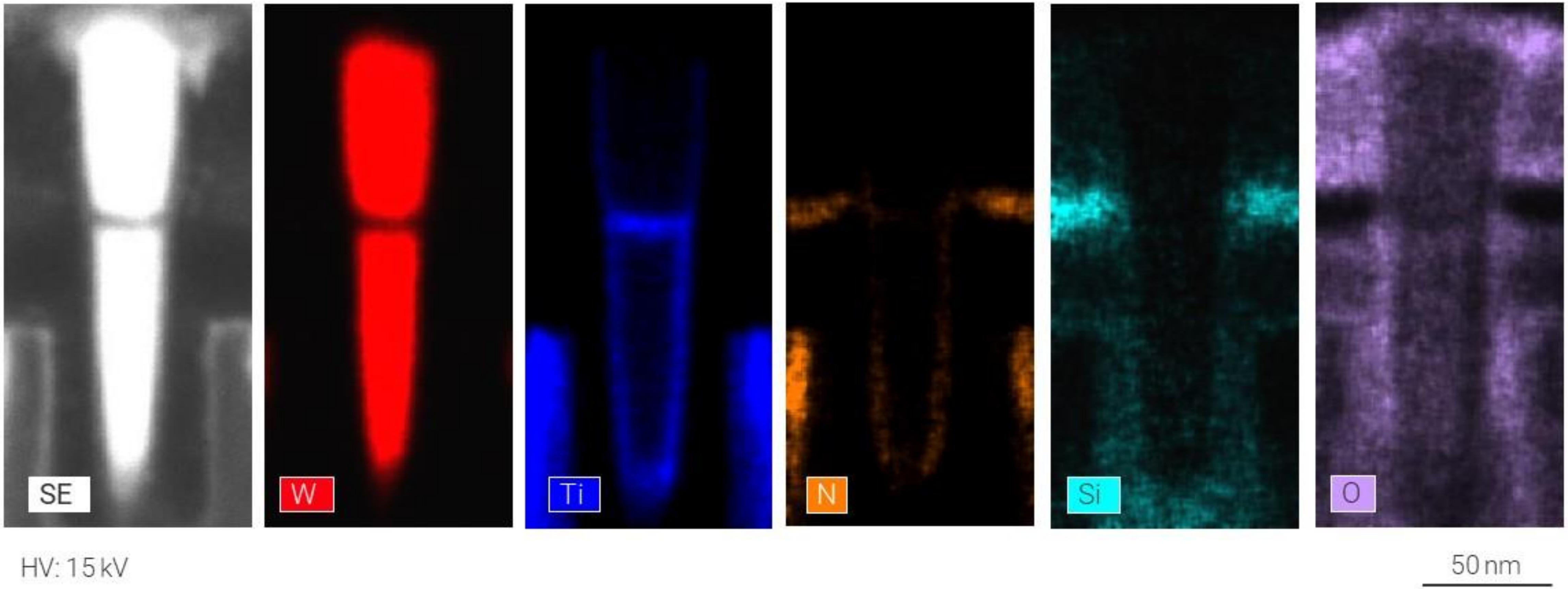
HV: 15 kV

50 nm

15 kV / 321 pA PC / 830s / OCR 19,400 cps

14 nm node FinFET – Gate cut lamella ~ 30 nm
Chemical mapping of complex structures at UHR

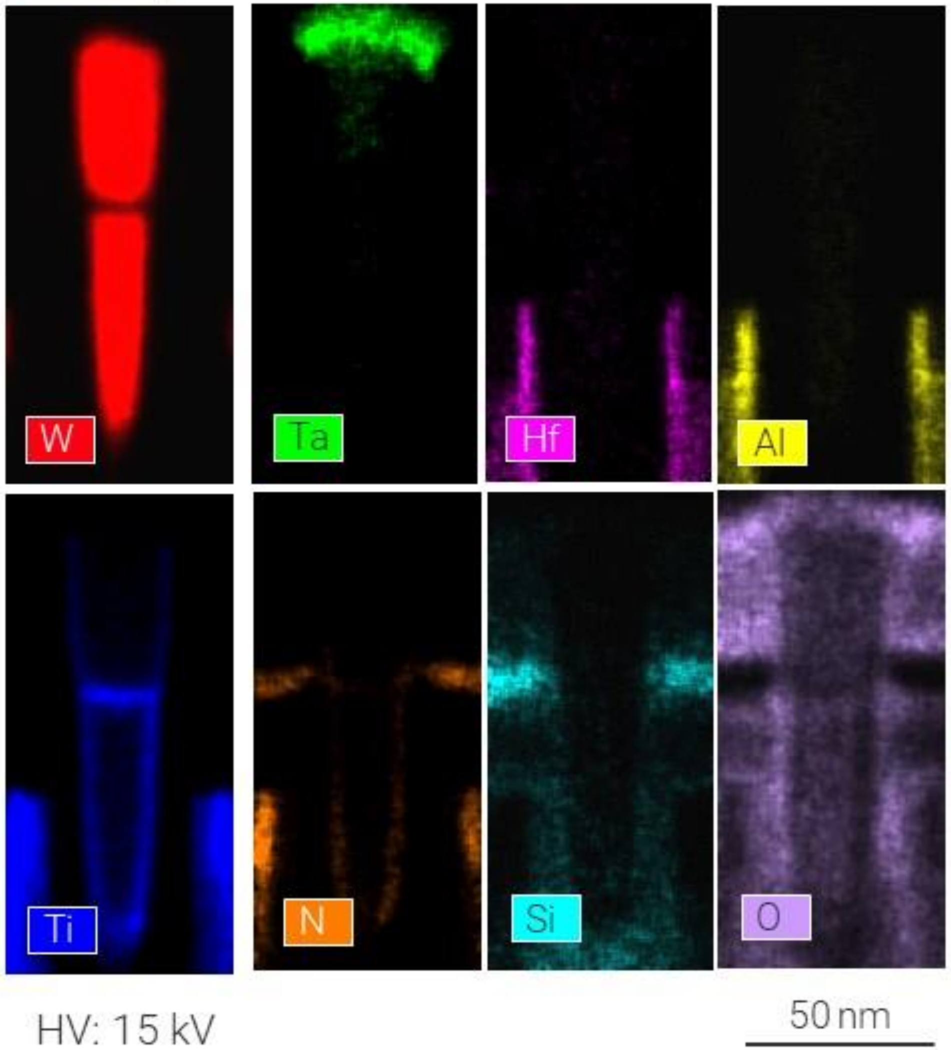
100 mm²



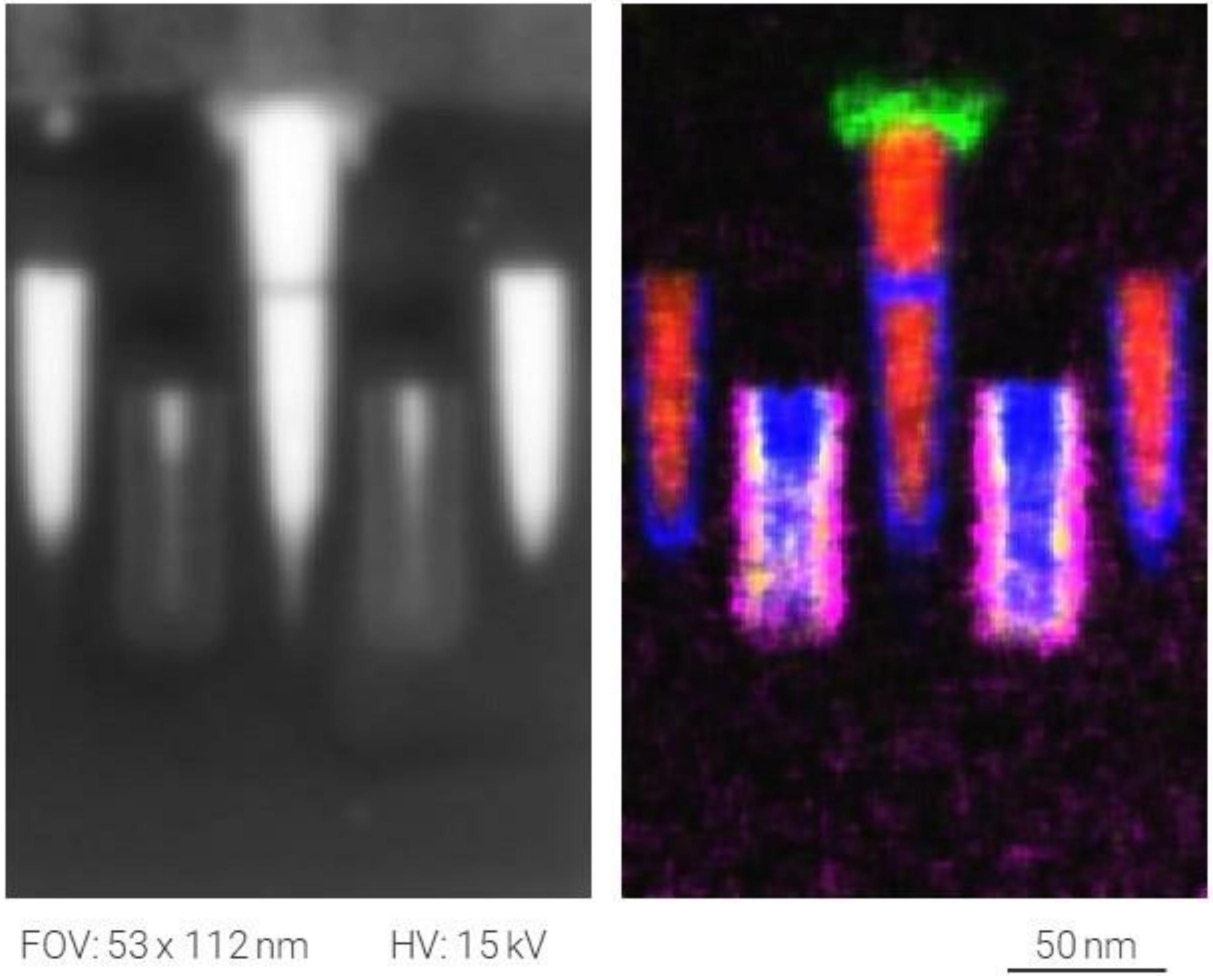
15 kV / 321 pA PC / 830s / OCR 19,400 cps

14 nm node FinFET – Gate cut lamella ~ 30 nm
Chemical mapping of complex structures at UHR

100 mm²

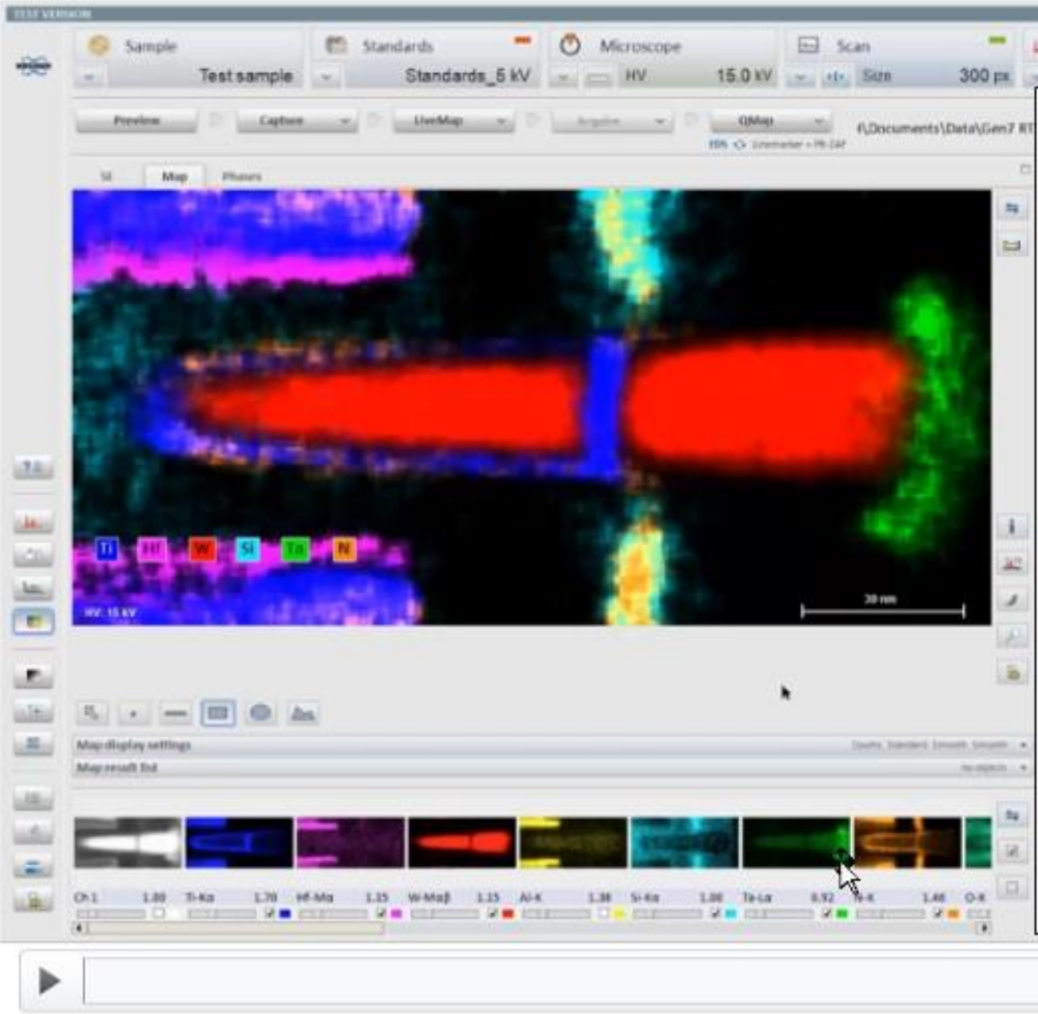


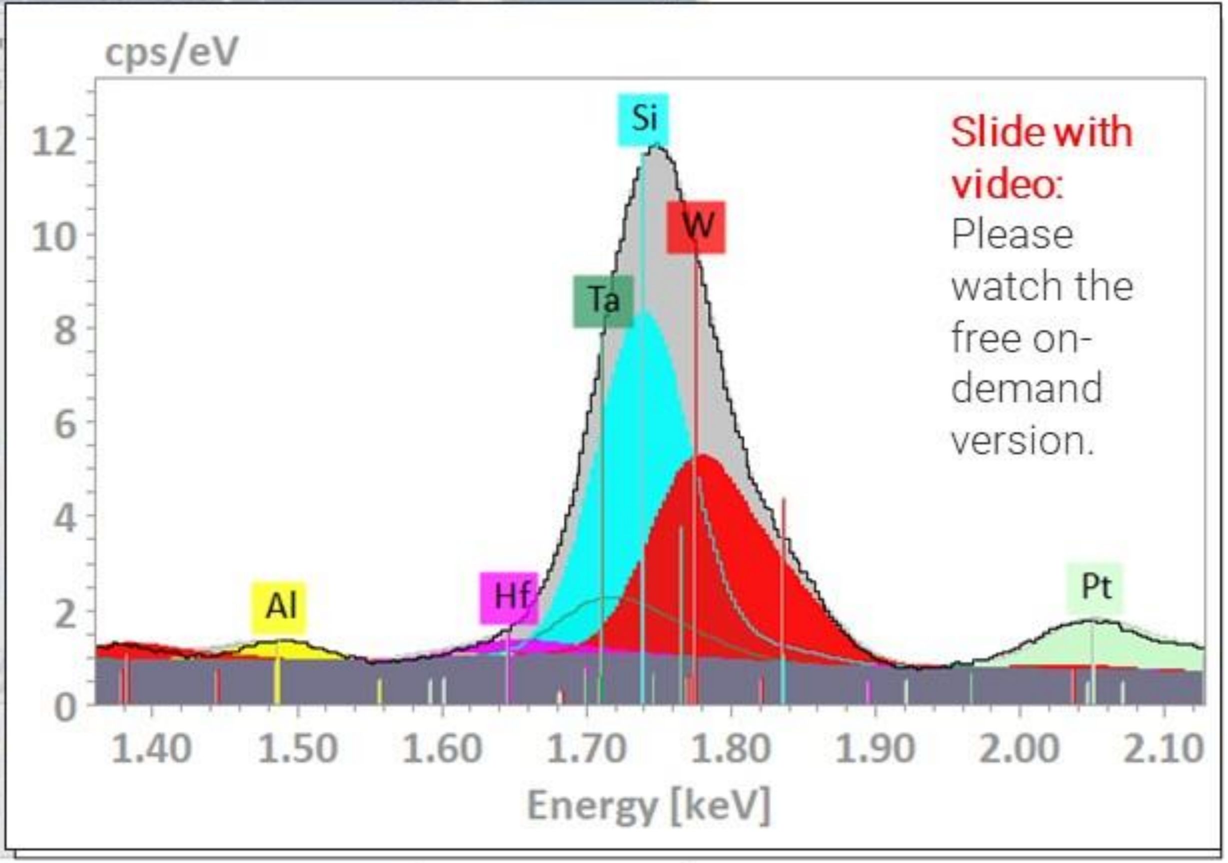
15 kV / 321 pA PC / 830s / OCR 19,400 cps



14 nm node FinFET – Gate cut lamella ~ 30 nm
Deconvolution of strong peak overlaps: Video

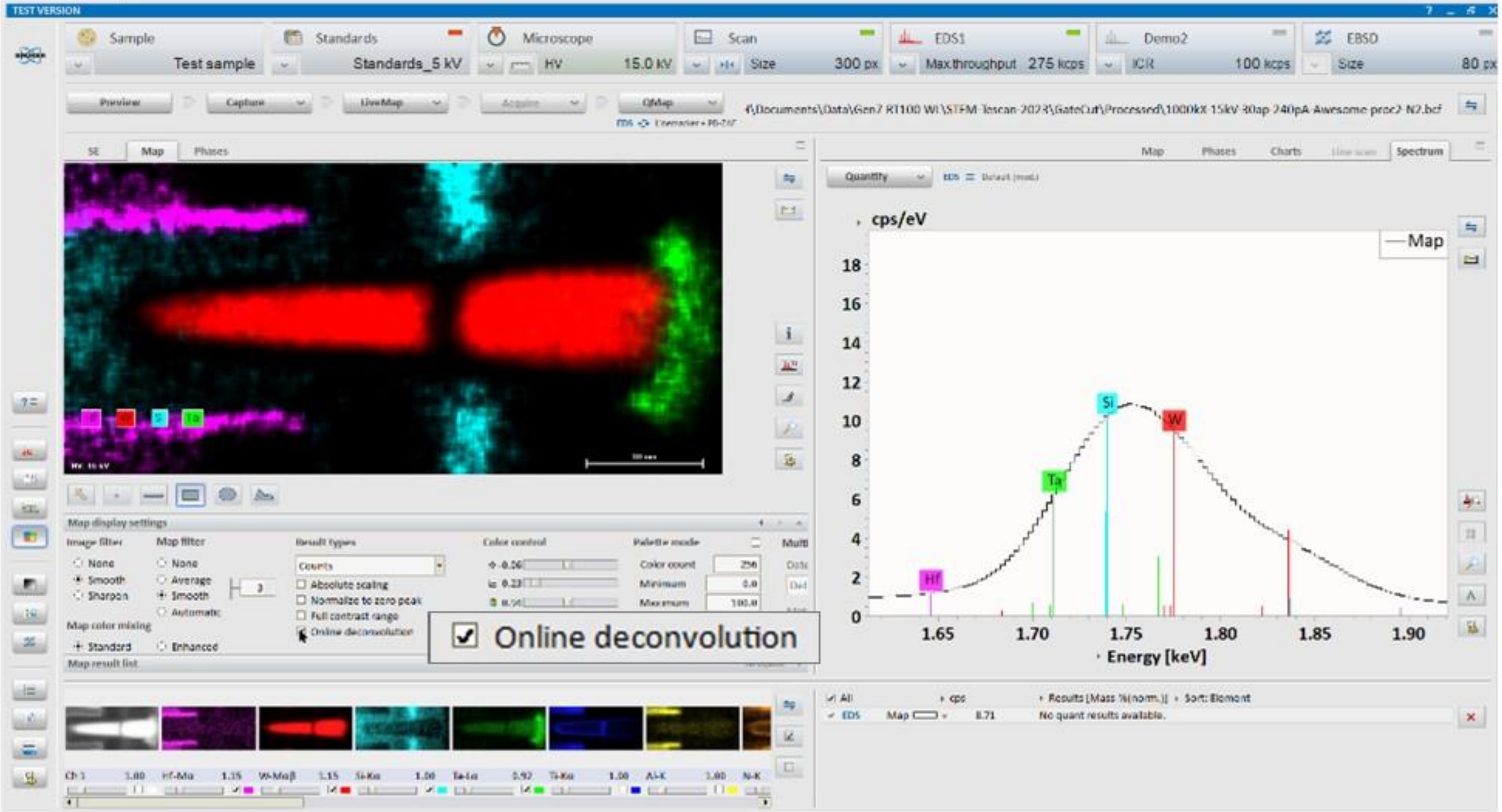
100 mm²





14 nm node FinFET – Gate cut lamella ~ 30 nm
..with “Online deconvolution” – inbuilt function

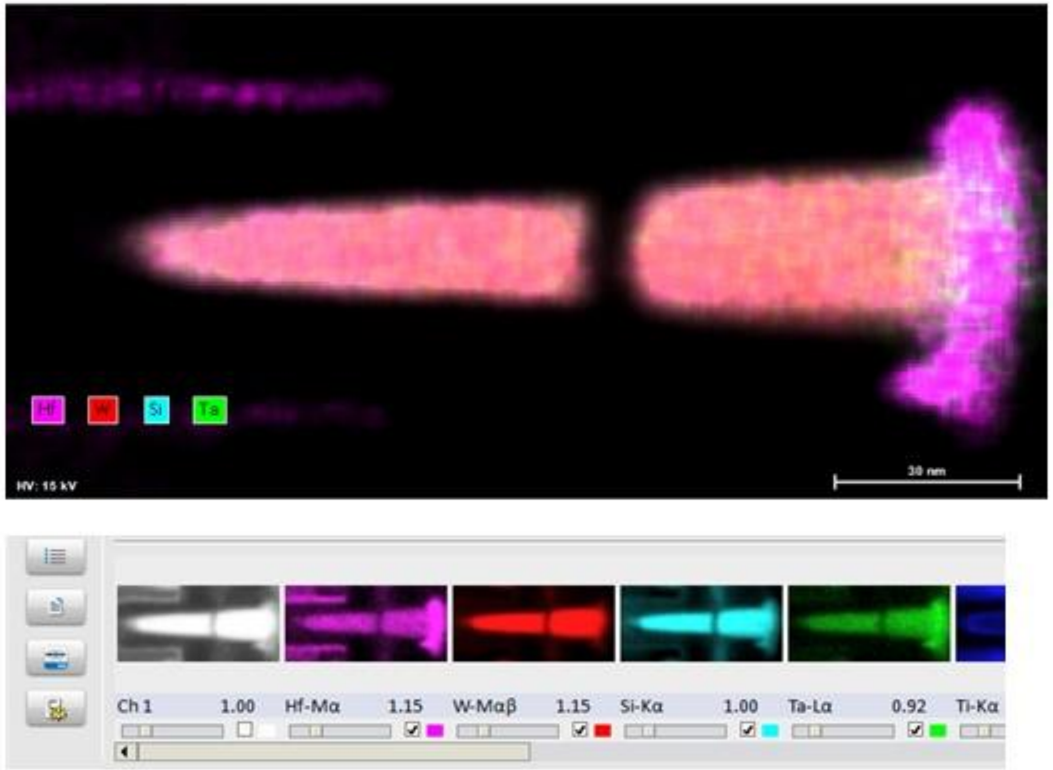
100 mm²



14 nm node FinFET – Gate cut lamella ~ 30 nm
..with "Online deconvolution" – inbuilt function

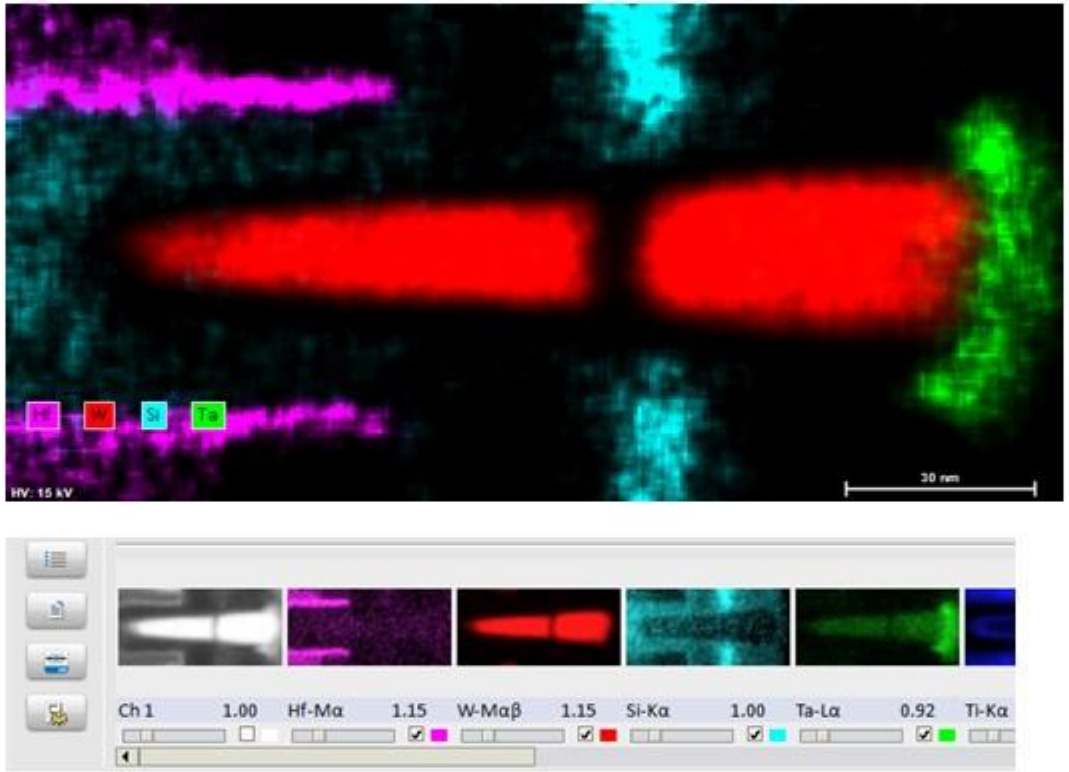
100 mm²

Before deconvolution



☐ Online deconvolution

After deconvolution



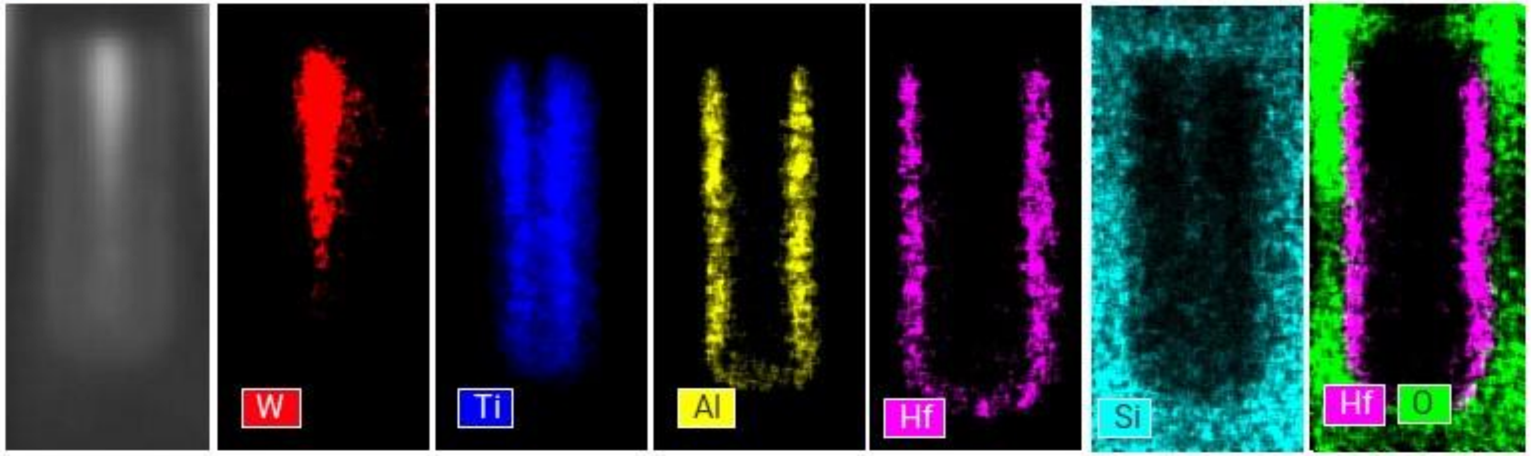
☑ Online deconvolution

14 nm node FinFET – Gate cut lamella ~ 30 nm

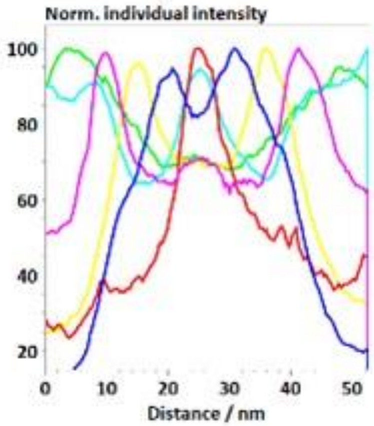
Discerning differences in chemical distribution at UHR

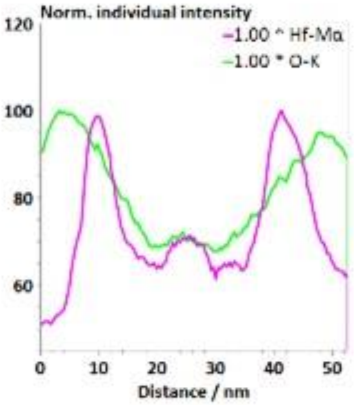
100 mm²

15 kV / 321 pA PC / 1174s / OCR 21,100 cps

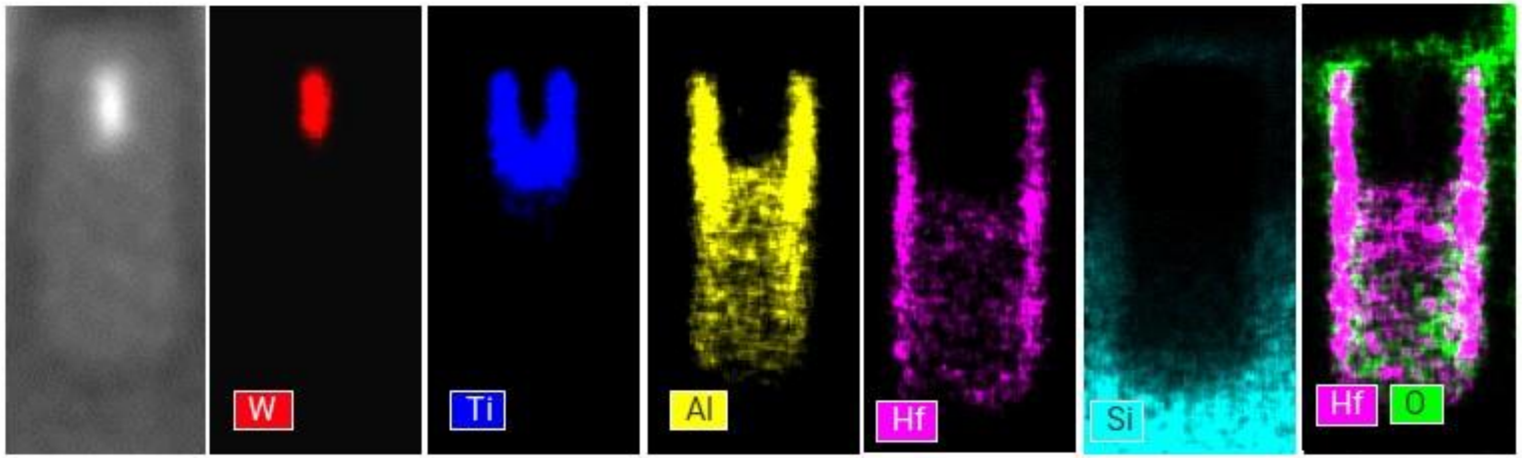


HV: 15 kV FOV: 53 x 112 nm 20 nm

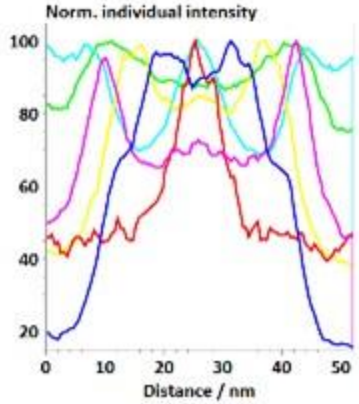


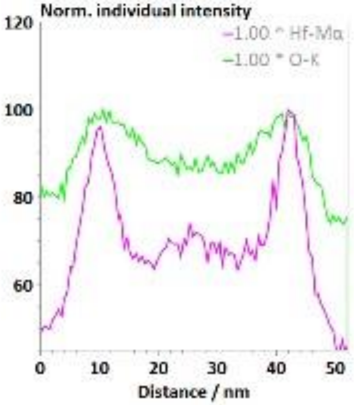


SiO_2 layer



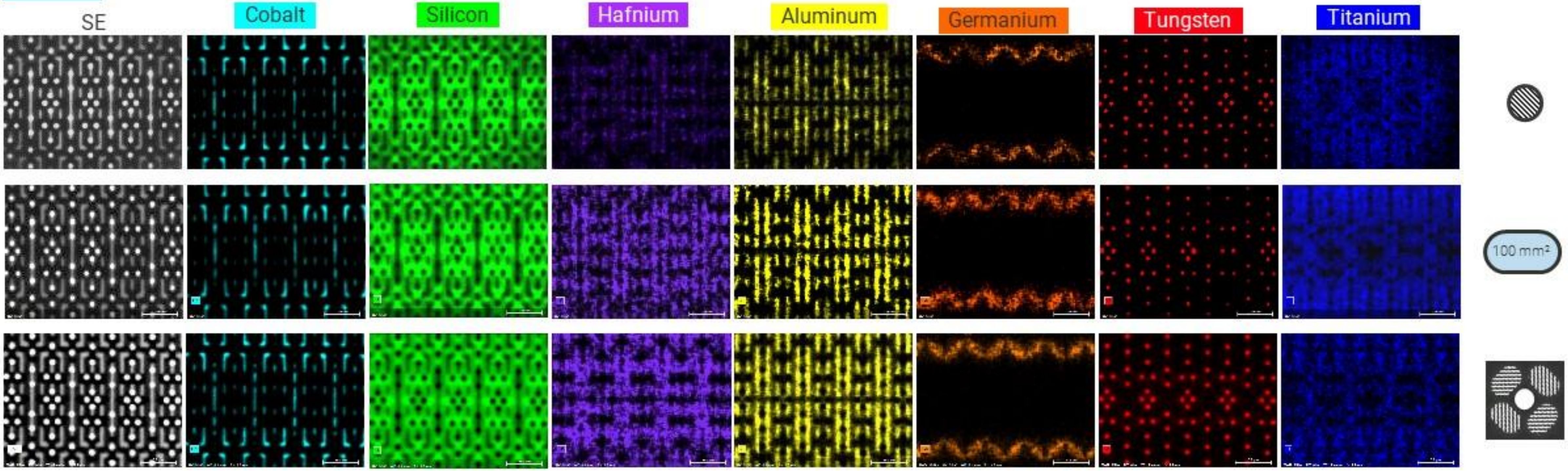
HV: 15 kV FOV: 53 x 112 nm 20 nm





HfO_2 layer

Detector comparison – Bulk sample at 5 kV
XFlash® 760 / Oval 100mm² WL / FlatQUAD: Output counts



HV: 5 kV Probe current: 1.1 nA

500 nm

3600s / OCR 12,200 cps

627s / OCR 31,300 cps

120s / OCR 309,000 cps

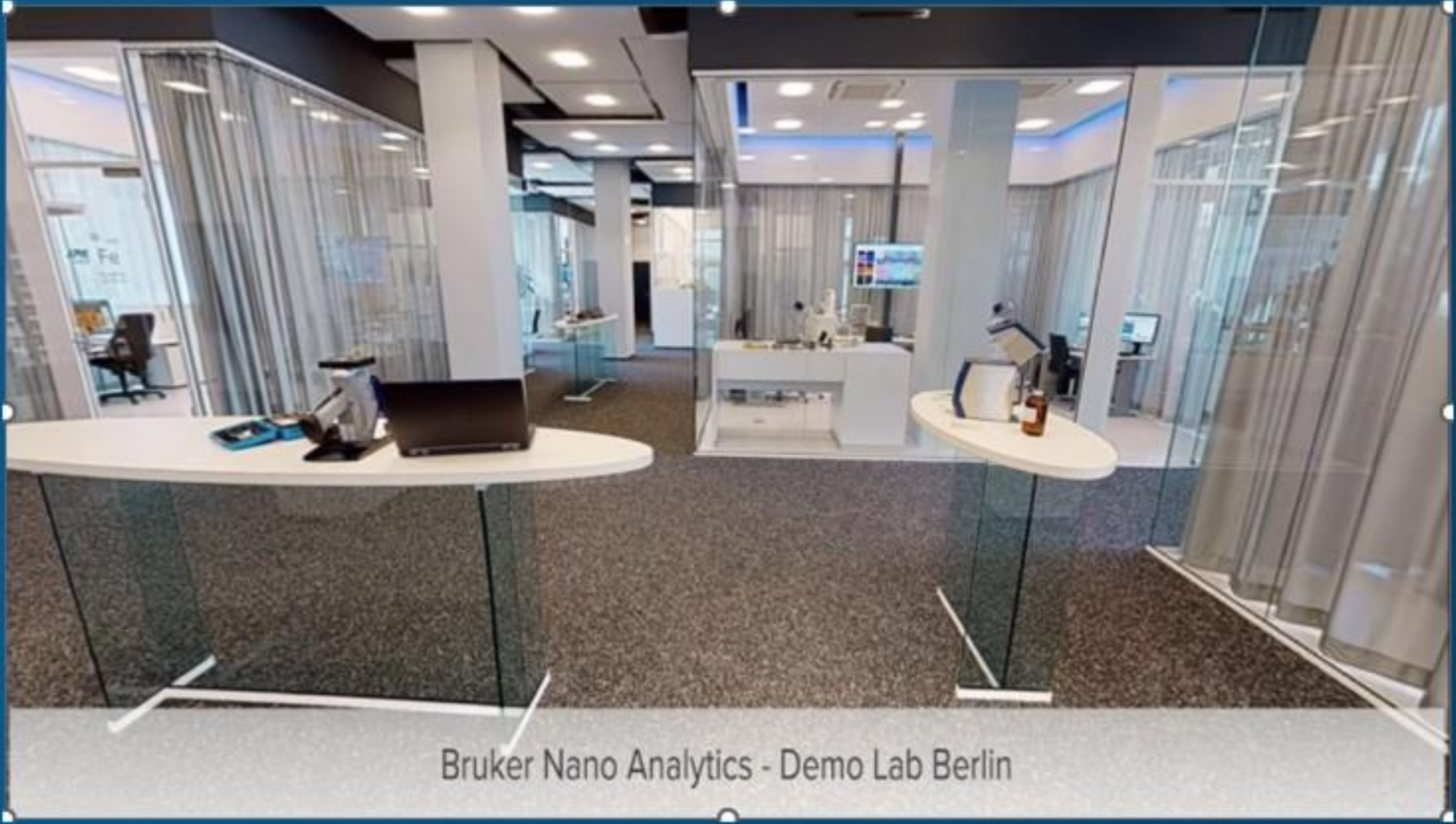
Summary

How to achieve ultra high resolution?

Drift correction | Interaction volume | Material density/matrix | Beam footprint | Pixel/map Size/statistics | Dwell time compromise | Beam conditions

- **HW requirements:** Beam alignment, probe current, environment control – mechanical/magnetic interactions.
- **Analytical detectors:** High collection efficiency EDS detectors; stable, efficiency and high throughput HW or electronics, backed by a powerful SW.
- **Specimen requirements:** Specimen thickness, matrix, mounting, contamination control.
- **XFlash® FlatQUAD:** Highest sensitivity (few pA) with 1.1 sr solid angle, suitable for low and high kV analysis.
  - Optimized for speed and sensitivity for challenging applications. 
- **XFlash ® Oval 100mm^2 windowless:** Ultra high EDS spatial resolution capable detector. 

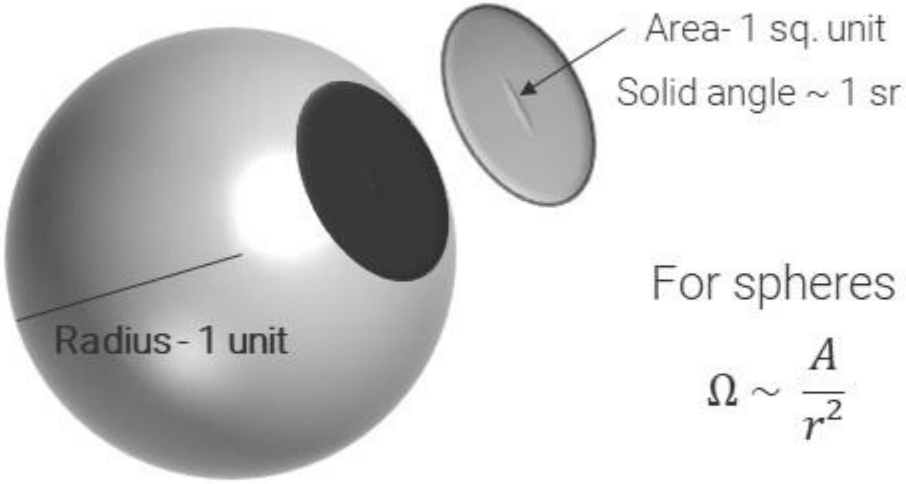
  - Light element, low kV low probe current analysis with high sensitivity, TEM-like EDS measurements in SEM.



Thank you!

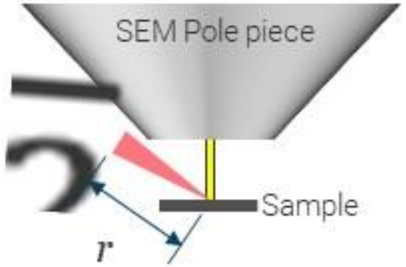
Innovation with Integrity

Bruker XFlash® EDS detectors
Solid angle



For spheres

$$\Omega \sim \frac{A}{r^2}$$



A = 100 mm^2
r = 15 mm
Ω = 0.44 sr

A = 60 mm^2
r = 12 mm
Ω = 0.416 sr

A = 100 mm^2
r = 14 mm
Ω = 0.51 sr

A = 60 mm^2
r = 11 mm
Ω = 0.495 sr

A = 100 mm^2
r = 13 mm
Ω = 0.591 sr

A = 60 mm^2
r = 10 mm
Ω = 0.6 sr

Every mm counts!

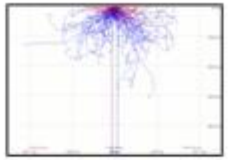
Corrected formula for flat surfaces e.g., SDDs (used by Bruker)

$$\Omega = \frac{A_{corr}}{(r + \Delta r^2)}$$

Summary

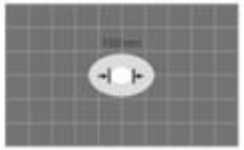
How to achieve ultra high resolution?

Interaction volume

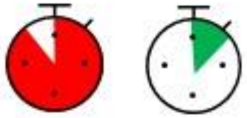


Material density/matrix

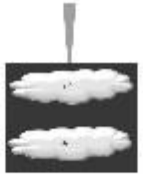
Beam footprint



Pixel/map Size/statistics



Dwell time compromise



Beam conditions

Drift correction

Hardware	Analytics	Specimen
UHR capable SEM	High solid angle/sensitivity	Minimize contamination
SE resolution -> EDS res.	Stable and efficient electronics for pulse processing	Specimen mounting
Environment – External vibrations/Magnetic fields	Stray radiation - x-rella	Contamination control -> Plasma cleaning

Semiconductor sample preparation

in-situ using TESCAN SOLARIS / SOLARIS X

Maksym Klymov

Senior Application Specialist – Semiconductors

29.06.2023

TESCAN – Tradition in innovative charged particle optics

Continuing over 60 years of electron microscopy tradition in Brno, Czech Republic

- The first EM assembled at the TU Brno at the end of the 1940‘s
- Former Tesla Brno manufactured over 3 000 devices (TEM + SEM) 1950-1990
- TESCAN was founded by former scientists, engineers and managers of Tesla Brno (1991)
- First digital SEM TESCAN VEGA (1999)
- First TESCAN FIB-SEM system with Orsay Physics FIB (2007)
- World’s first integrated Plasma FIB-SEM (2011)

TOH Headquarters

1951

Tesla BS241

2007

TESCAN LYRA FIB-SEM

Today

TESCAN SOLARIS X

TESCAN BRNO - Production facility and RnD

TESCAN – Tradition in Innovative Charged Particle Optics

ORSAY PHYSICS
TESCAN ORSAY HOLDING

30 years of experience and leadership in Focused Ions Beams and Gas Injection System technology

- World's first convergent beam chamber FIB / SEM developed for IBM (1990)
- First commercial FIB OEM columns (1997)
- World's first ECR Plasma FIB-SEM (2011)

…

1990'

Ga FIB

2011

iFIB – Plasma FIB

Today

Nanospace

Orsay Physics – Fuveau, France

TESCAN Portfolio

SEM

Thermal Emission SEM

FEG-SEM

Special Solutions

FIB-SEM

Ga FIB-SEM

Xe plasma FIB-SEM

Systems for TEM sample preparation in Semiconductors

Micro-CT

4D STEM

TESCAN SOLARIS X

A Plasma FIB-SEM platform for deep sectioning and the highest resolution end-pointing for package level failure analysis

- Efficient and fast physical failure analysis using rapid artifact-free FIB milling
- Investigation of deeply buried structures in a large area – up to 1 mm
- Nanometer-precision milling control thanks to high resolution end-pointing at FIB-SEM coincidence
- The most beam-sensitive materials imaged in UHR with excellent surface sensitivity and high material contrast
- High quality TEM samples prepared with negligible beam damage and Ga-free
- Even the most challenging composite samples (OLED and TFT displays, MEMS devices, isolation dielectrics) processed effectively
- Boosting productivity utilizing advanced workflows in Essence™ graphical user interface

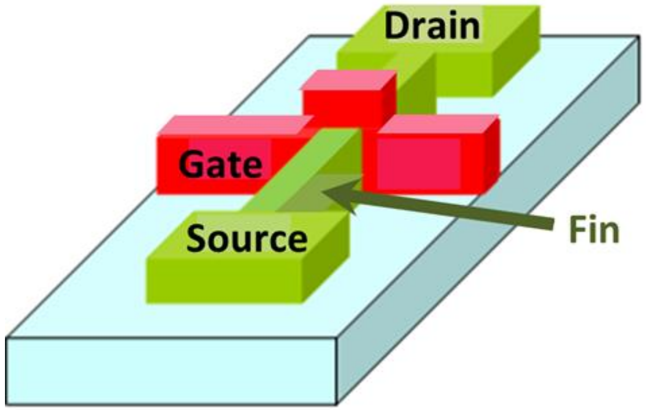
TESCAN SOLARIS

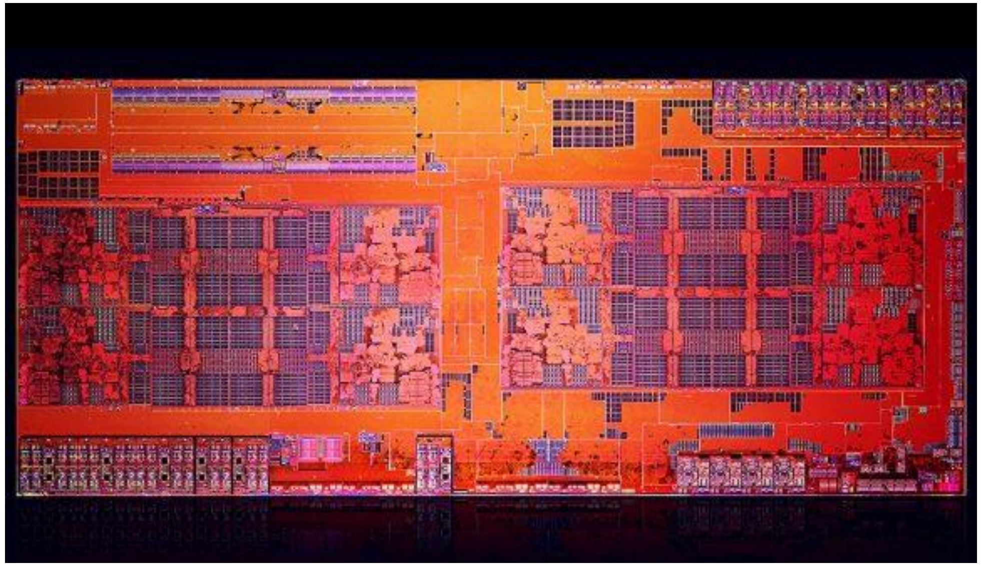
A solution for semi-automated high-quality TEM lamella preparation

- **Prepare ultra-thin TEM samples easily from sub-10 nm semiconductor technology nodes** using advanced dedicated workflows included in TESCAN‘s Essence GUI
- **Create high quality TEM samples with negligible beam damage** using gentle FIB milling down to 500V beam energy for final polishing
- **Investigate your structures in inverted, planar and cross-lamella geometries,** which is easily achieved with our nanomanipulator in our proprietary below-FIB position
- **Shorten time to result with TESCAN AutoSlicer™** semi-automated TEM sample preparation module
- **Achieve nanometer-precision end-pointing when milling or cross-sectioning** using the high-resolution imaging capabilities of the Triglav™ SEM column
- **Perform UHR imaging on beam sensitive materials** with TESCAN‘s highest resolution Triglav™ SEM column, with immersion optics designed for excellent surface sensitivity and high materials contrast at the beam coincidence point
- **Ensure productivity for all users** by utilizing advanced workflows in TESCAN Essence™ graphical user interface

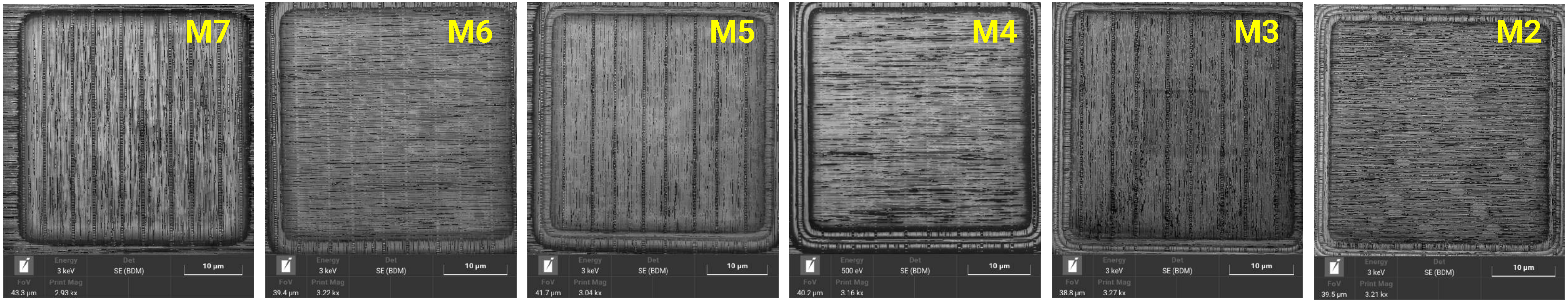
CPU based on 14 nm node technology

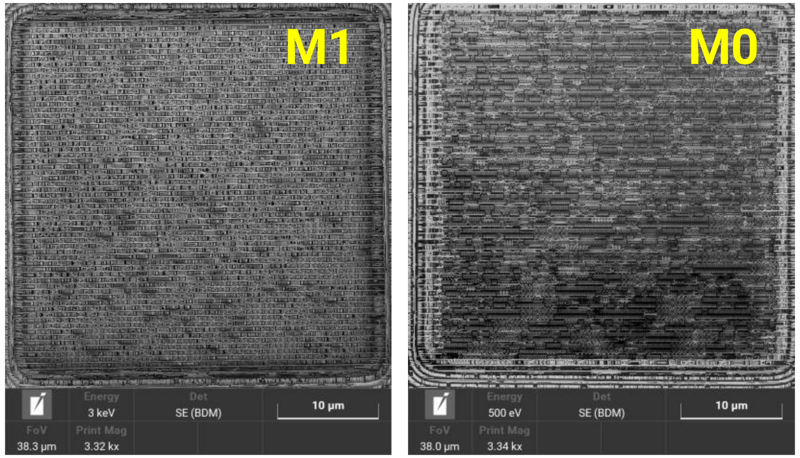
- TEM lamella was prepared from a 14 nm technology die. It helps to expose potential defects on the transistor contact level.
- The lamella can be prepared as a further step after delayering using **SOLARIS X** – fully in-situ without breaking the vacuum.

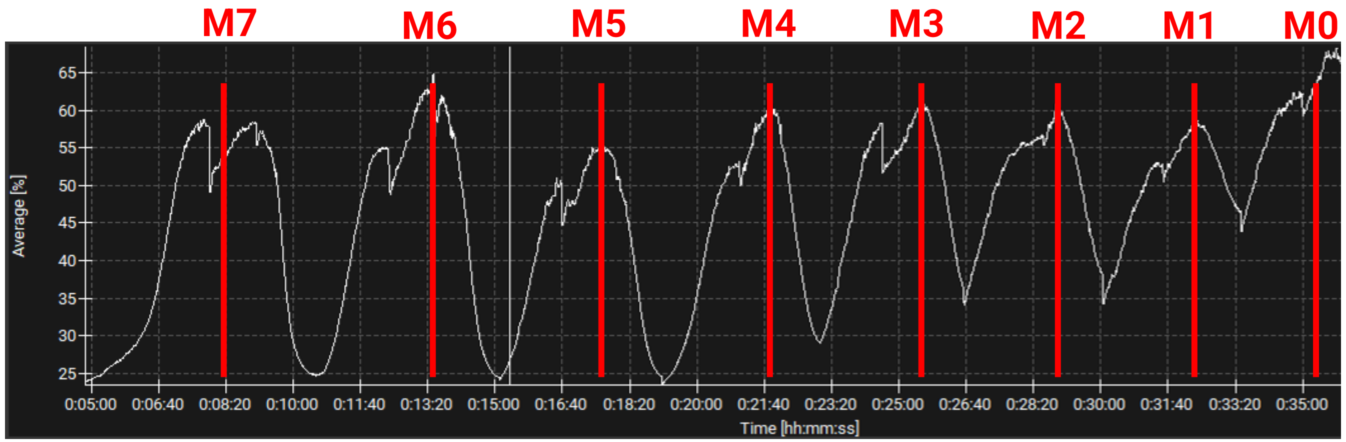




Gas-assisted top-down delayering



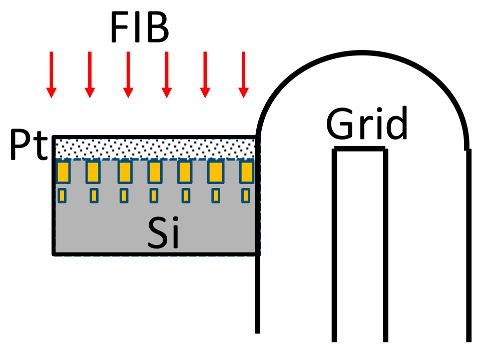




Monitoring of the process is based on collection the average secondary electron signal. Every peak corresponds with one of the metal layers. This feature allows to stop on a required level.

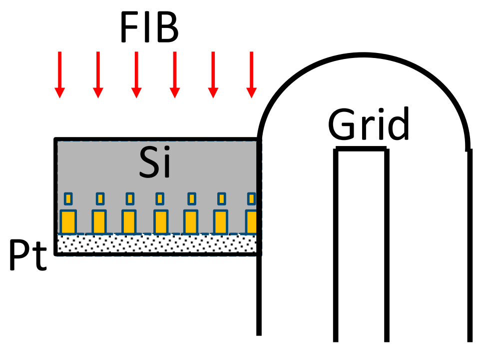
Common industry TEM lamella preparation strategies

Top-down



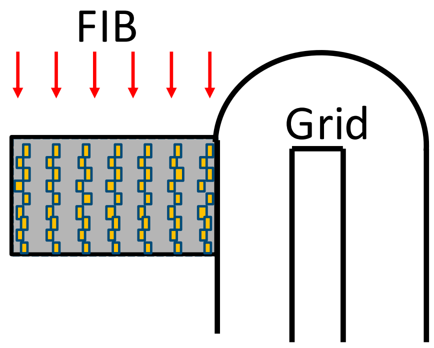
- *Thickness of the TEM sample > 50 nm*
- *Large depth to be thinned (> 1 µm)*

Inverted



- *Thin TEM sample to be prepared < 50 nm*
- *Small depth to be thinned < 1 µm (thin layers on surface, device region)*
- *Avoid curtaining on the substrate from the structures above*

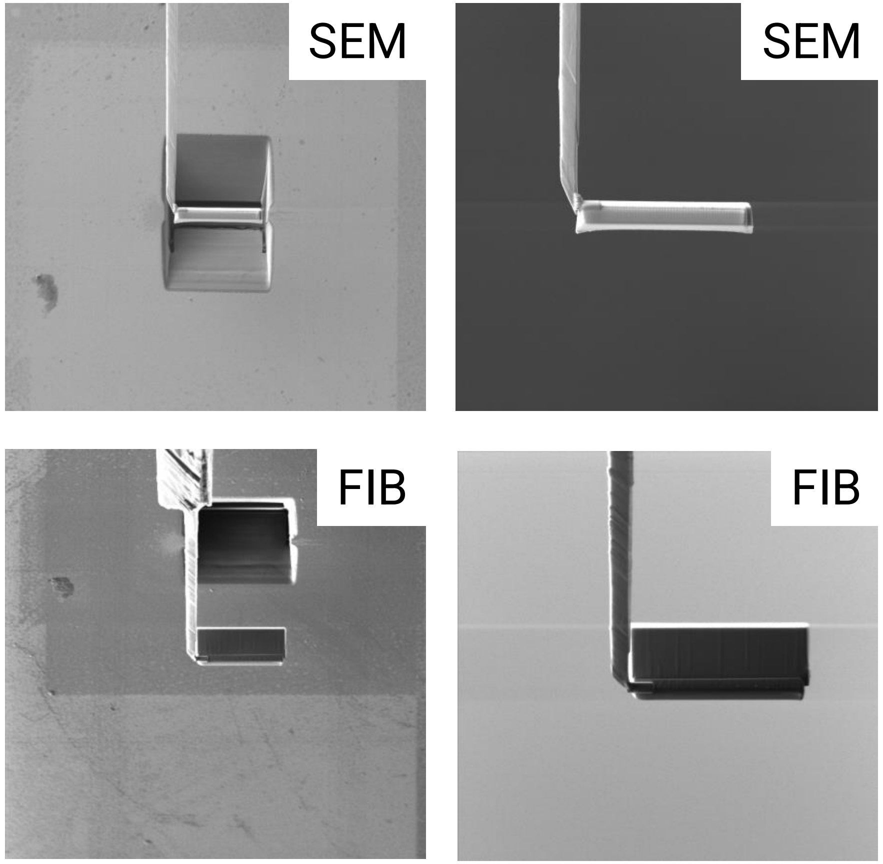
Planar



- *TEM sample parallel with the sample surface (3D NANDs, memory samples etc.)*

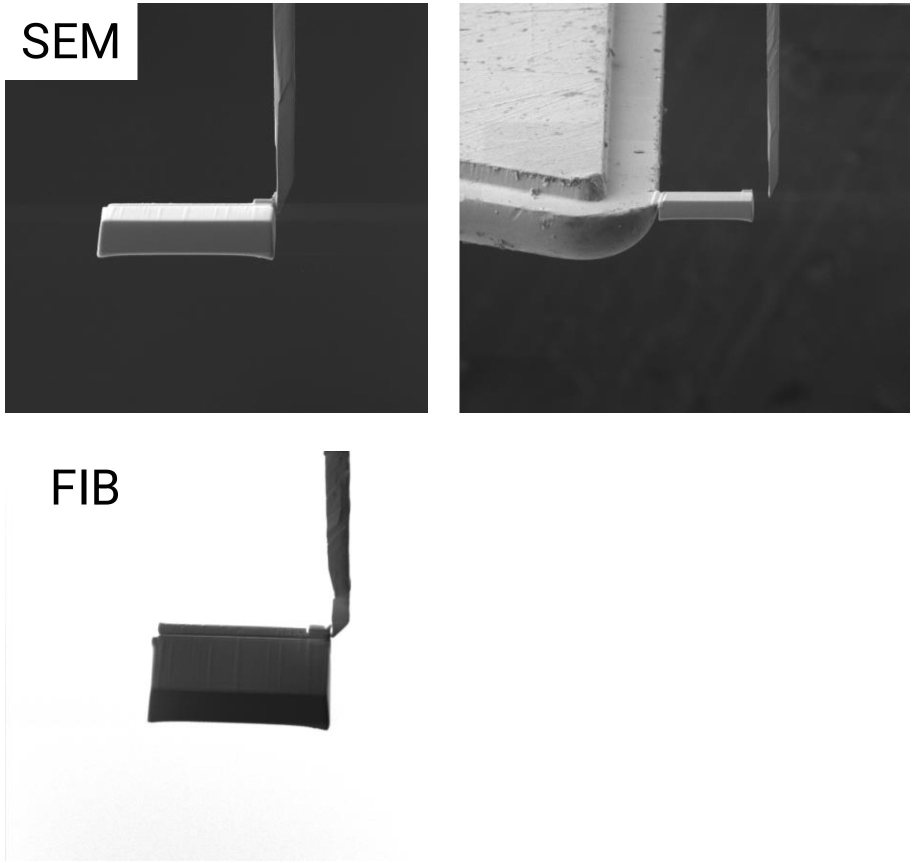
Inverted TEM lamella preparation

1. Extraction

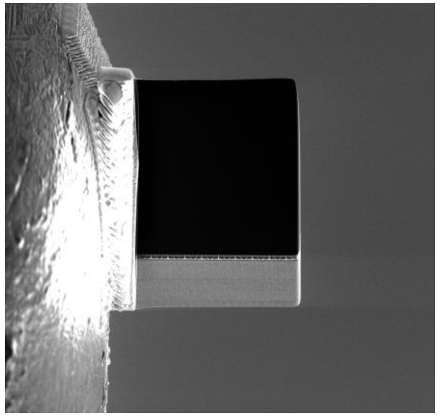


Probe rotation

2. Attachment

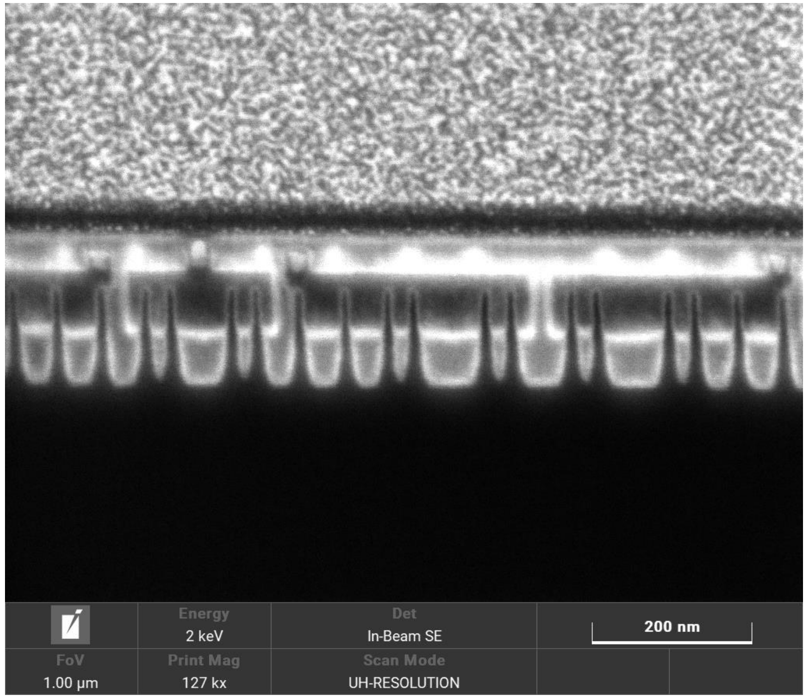


3. Polishing

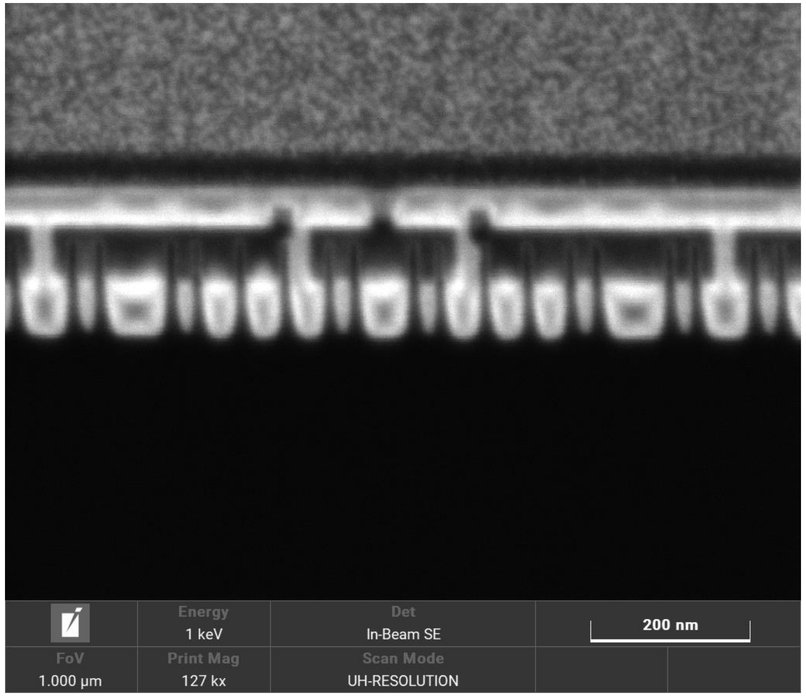


- Inverted TEM lamella is obtained in 1 step: Rotation of the nanomanipulator probe by 180°

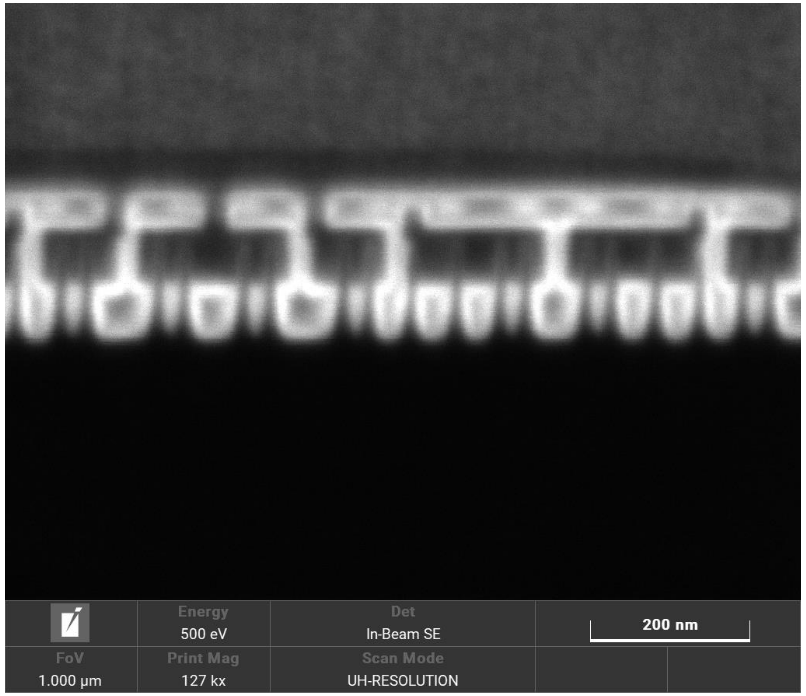
SEM end-pointing



a) SEM 2 kV In-Beam SE



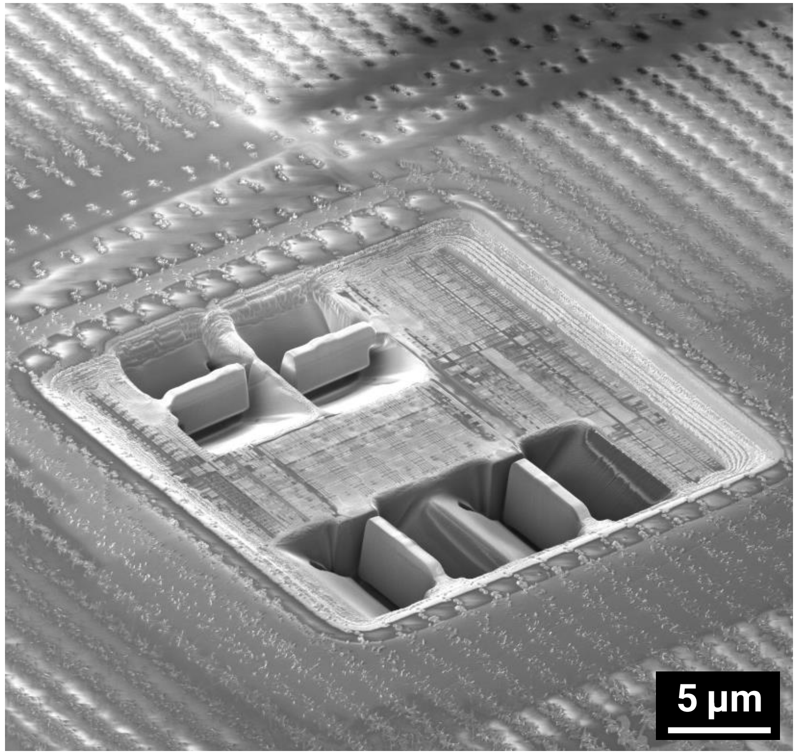
b) SEM 1 kV In-Beam SE



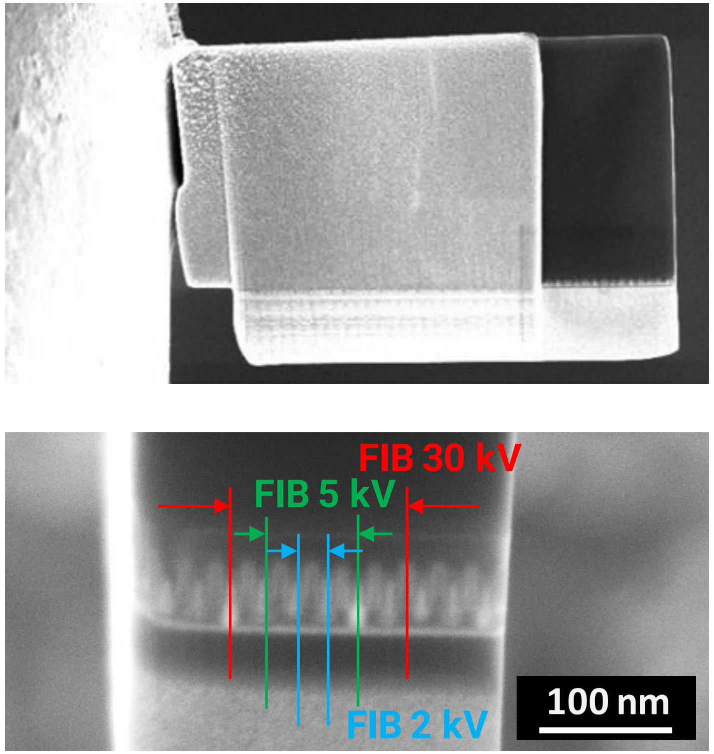
c) SEM 500 V In-Beam SE

- SEM low kV end-pointing during TEM lamella preparation

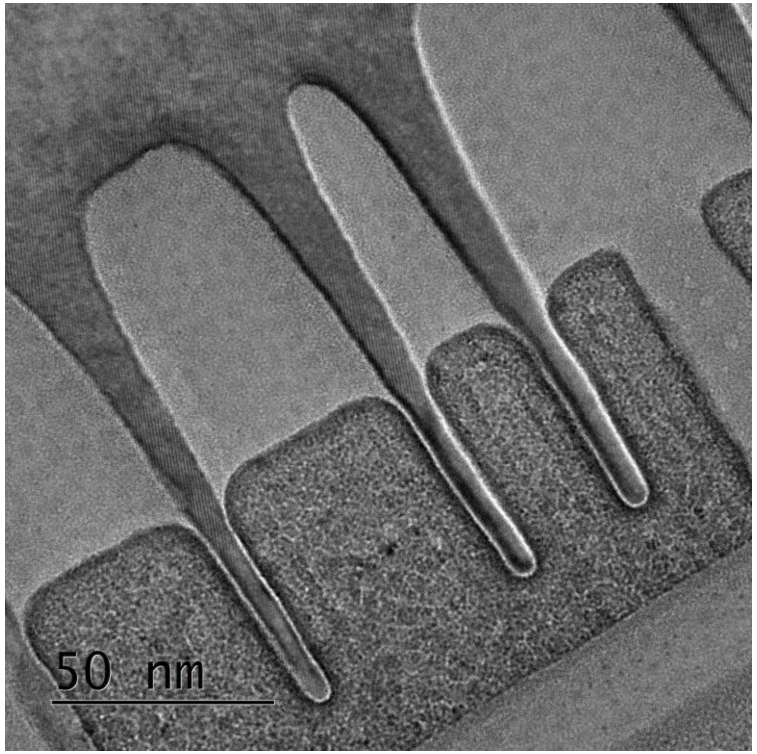
TEM lamella preparation



14 nm AMD Ryzen 3 sample



TEM lamella preparation process steps – side view



200 keV TEM image, final lamella thickness ~20 nm

Please, feel free to contact us through local TESCAN Sales representative in case you have any questions or suggestions for further analyses. Also, you are very welcome to visit our Demo Lab in Brno.