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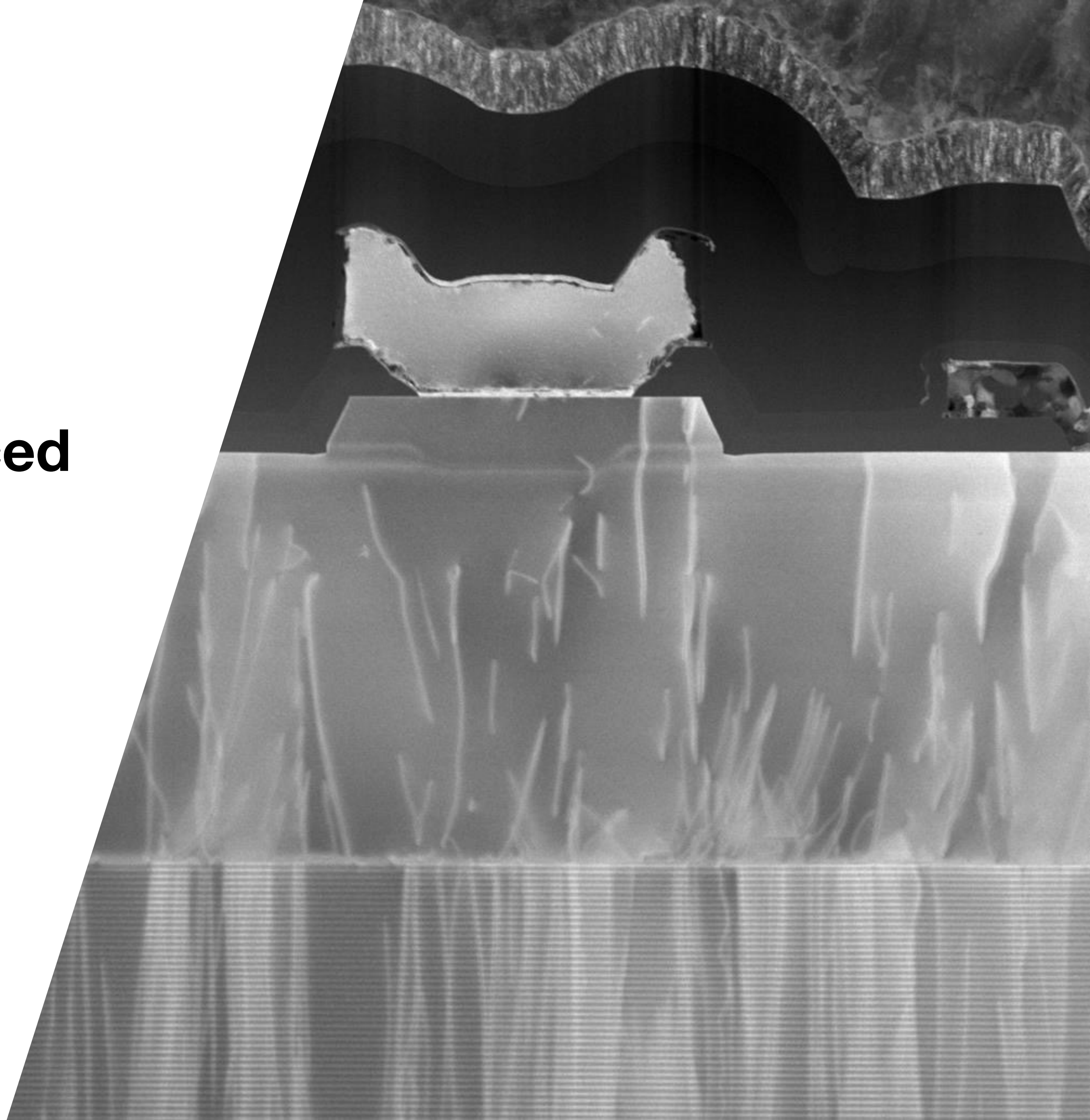


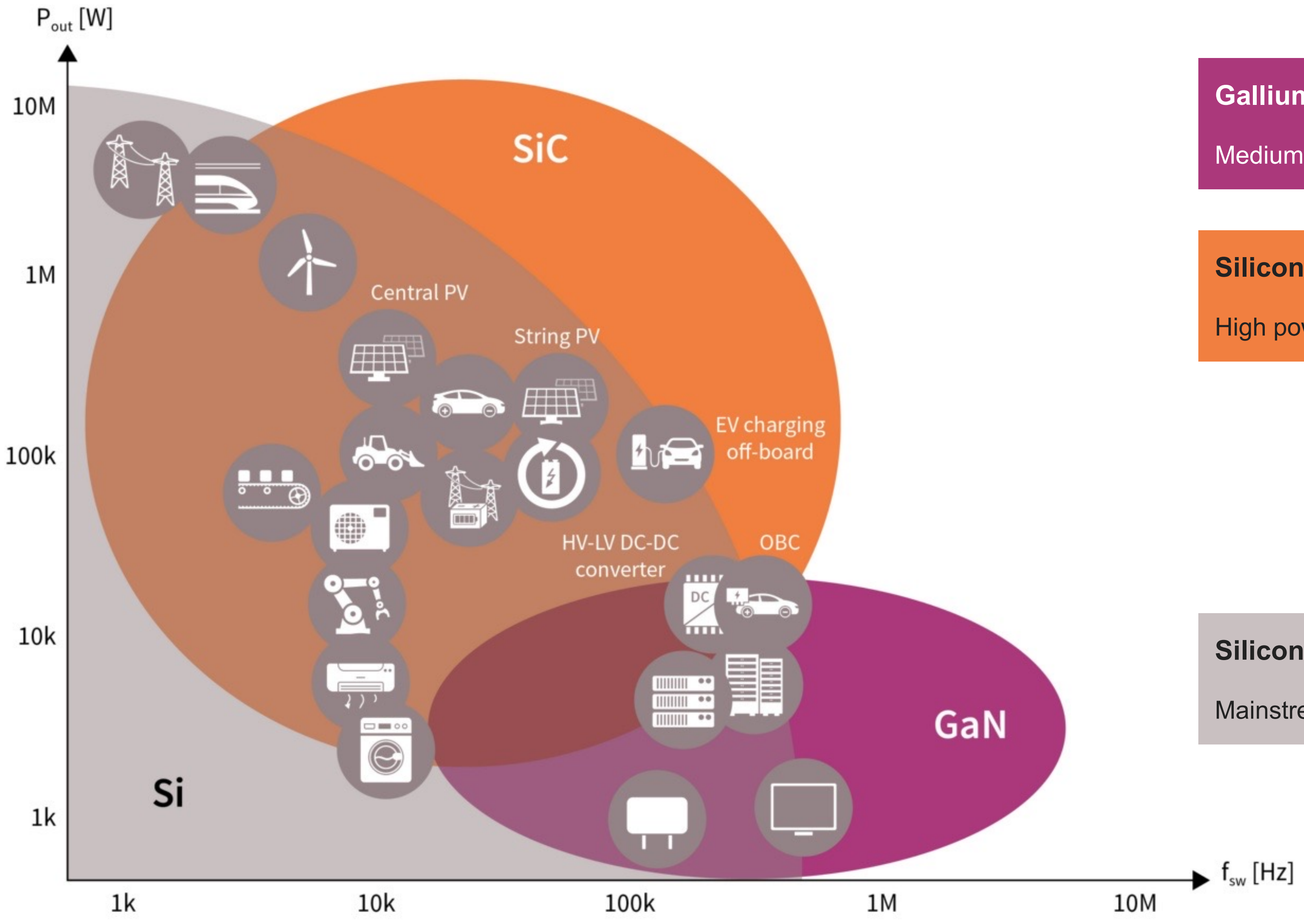
Sample preparation and TEM imaging techniques for advanced power devices

Antonio Mani

April 2024

The world leader in serving science

Power device Inflections



Gallium Nitride 100V – 650V

Medium power- highest frequency

Silicon Carbide 650V – 13.3kV

High power- high frequency

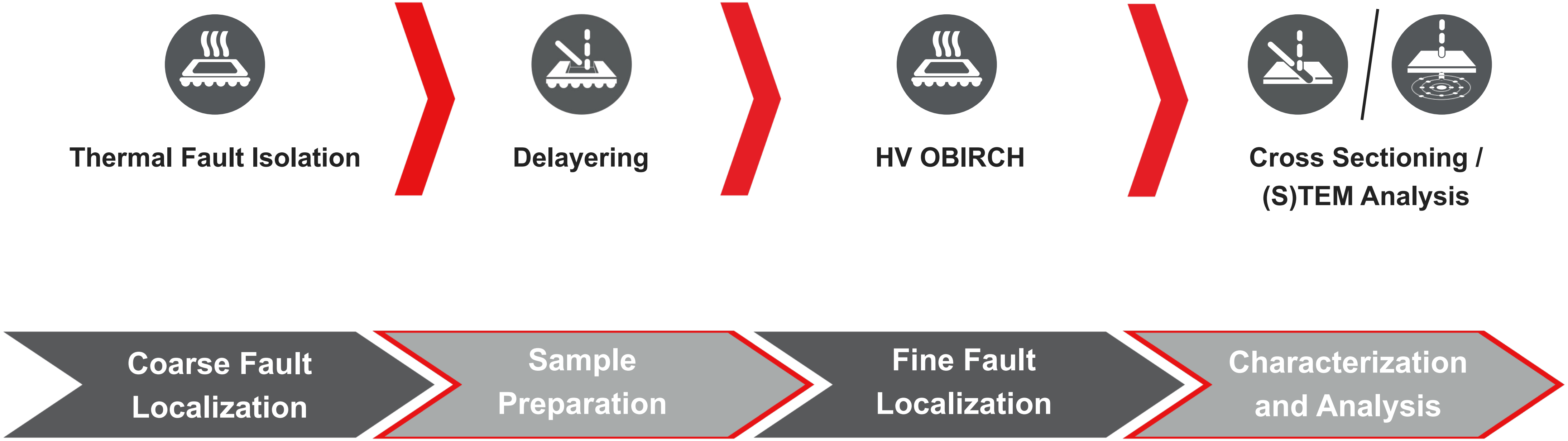
Silicon 25V – 1.7 kV

Mainstream technology

SiC & GaN ➔ higher performance ➔ high defectivity ➔ more analysis demands

*Chart courtesy of Infineon

EFA to PFA Workflow for Power Devices

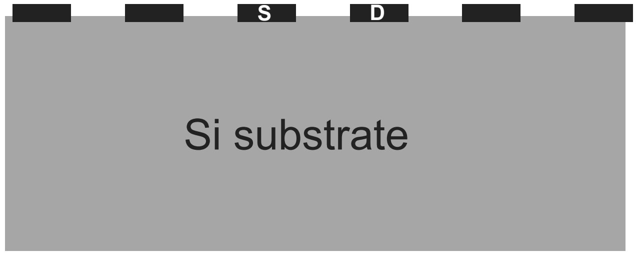


Power devices present unique failure analysis challenges

Logic & Memory Failure Analysis

√ Electrical / Optical defect localization

√ FIB/SEM imaging at ROI

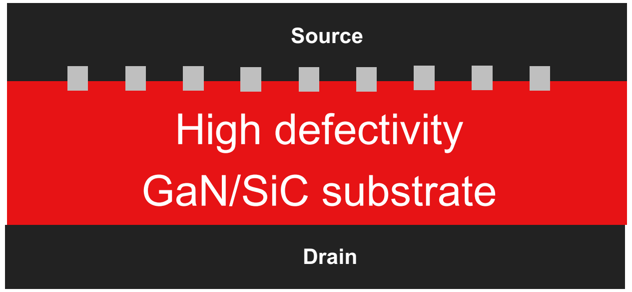


√ Optical probing

Power Device Failure Analysis

🚫 Photons blocked by metal

🚫 Large structures, high volume FIB milling

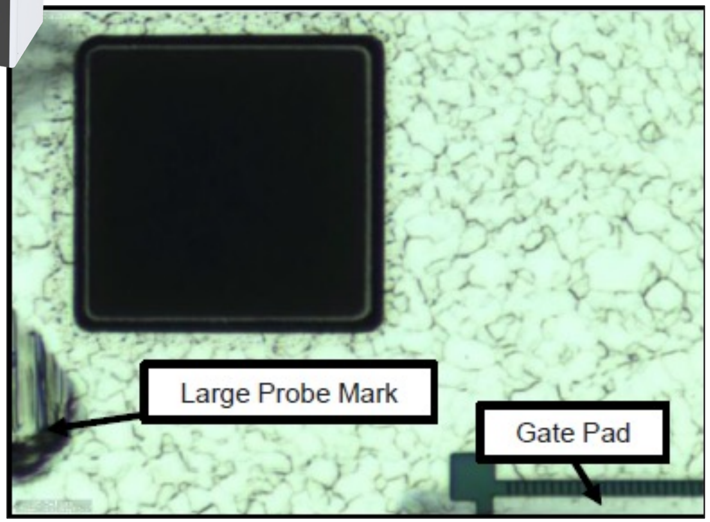


🚫 Photons blocked by metal

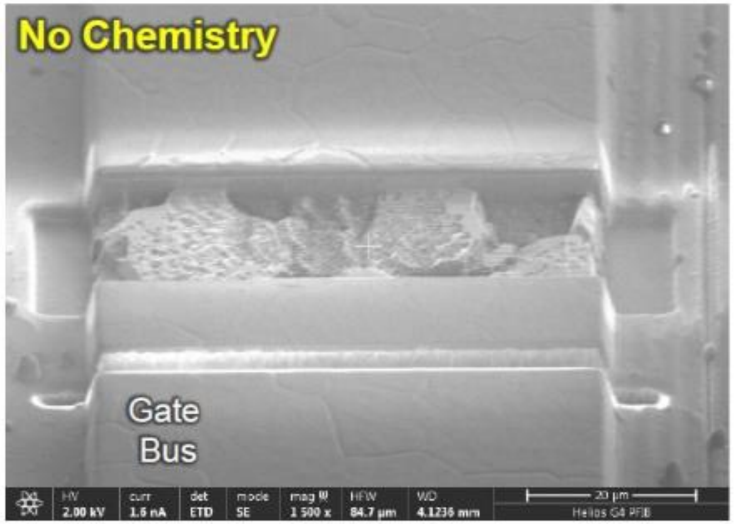
Power devices present unique failure analysis challenges

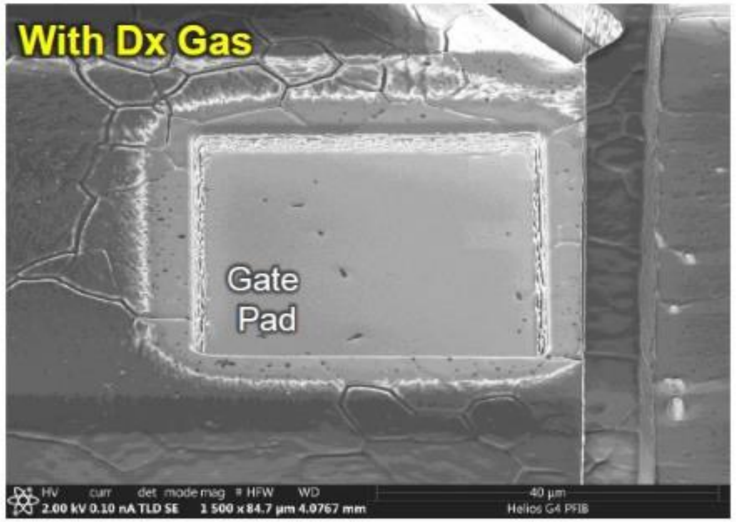
Automated Delayering Power Devices

Helios 5 PFIB/Hydra



Metal Delayering with Xe+



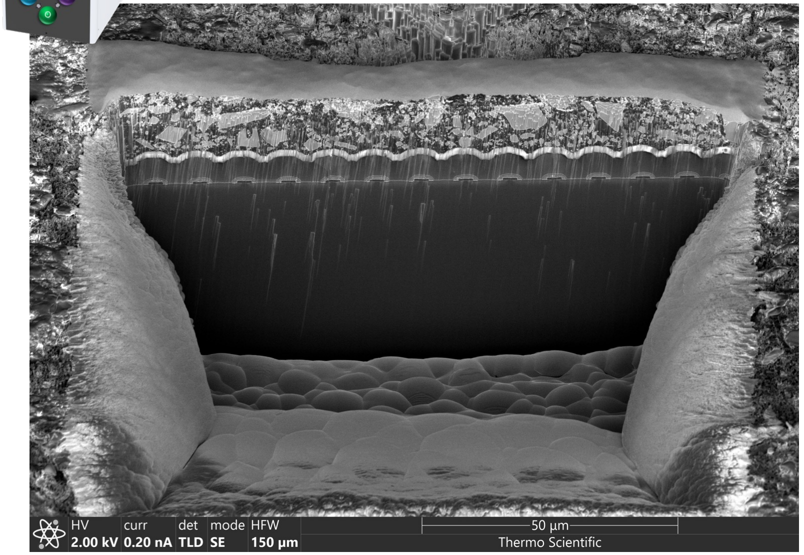
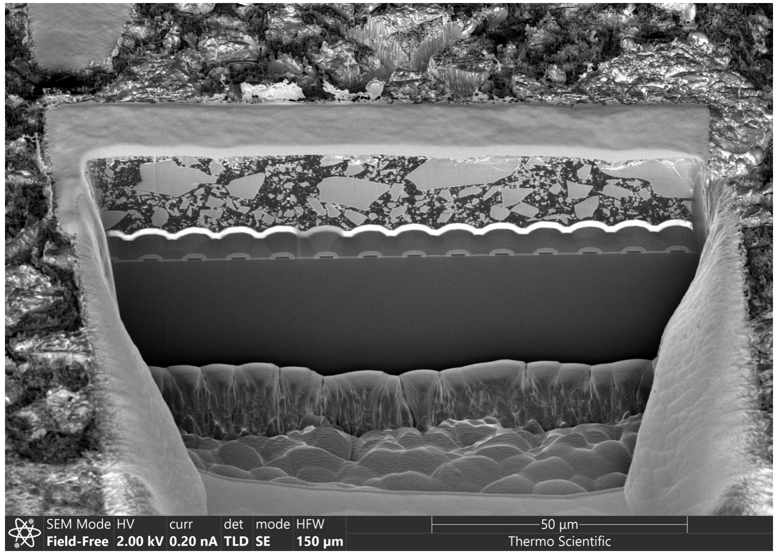
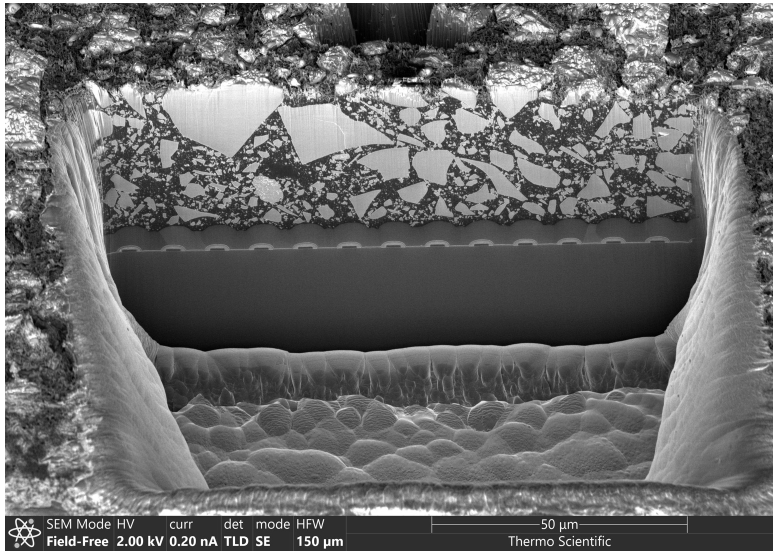


- Why delayering is necessary? **Thick aluminum/Ti/TiN layers prevents failure detection (photon signatures, electrical probing)**
- Why TFS' PFIB for delayering? **Planarity is essential for delayered regions which require proprietary chemistry, applications expertise, and uniform PFIB beams**

Large delayered windows (100 µm x 100 µm) only possible using Helios PFIB for power devices FA !

Why Helios 5 Hydra for Cross-Sectioning Power Devices?

Helios 5 Hydra

good	great	great
		
Xenon PFIB: 51m	Argon PFIB: 34m	Argon PFIB: 34m (No protective cap needed!)

- Regions of interest are large and require large volume removal
  - **Thermo Fisher Scientific PFIBs have the highest volume removal rates**
- Milling traditionally difficult materials such as SiC requires new technology for quick FA
  - **Argon PFIB has the highest max current (4µA) and unique ability to mill dissimilar materials quickly**

Why Helios 5 Hydra for Cross-Sectioning Power Devices?

Thermo Fisher SCIENTIFIC

Helios 5 Hydra

TPUT comparison for 120μm X-section:

Device	Ga^+ (note*)	Xe^+	Ar^+
GaN	500m	20m	13m
SiC**	1000m	51m	24m

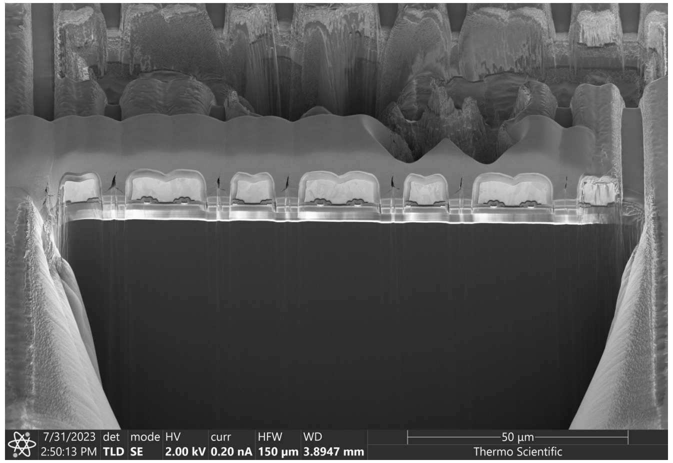
* Predicted

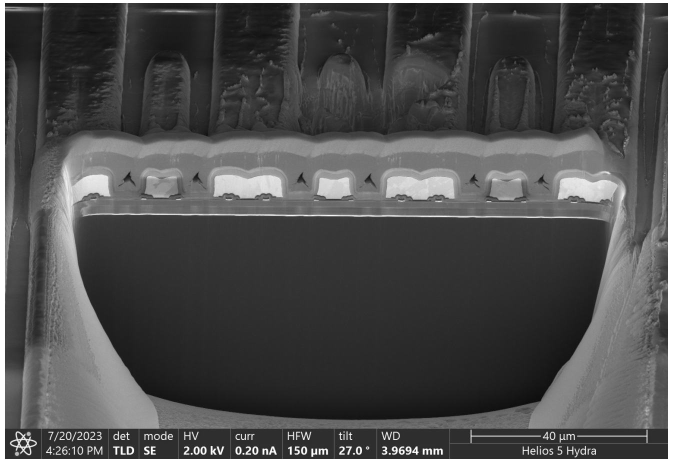
** Process results shown from previous slide

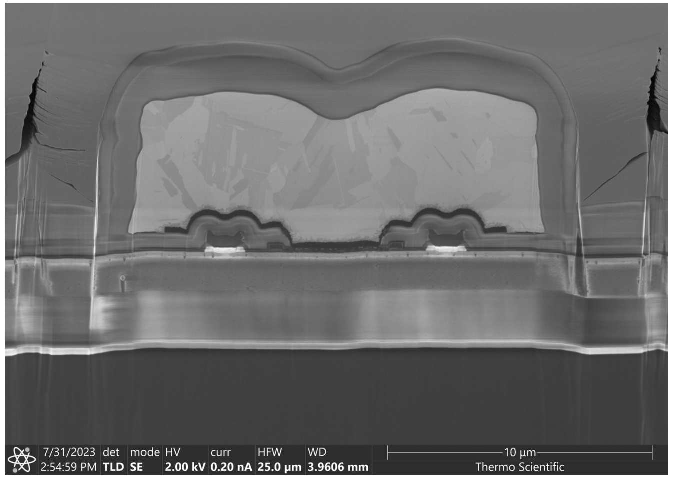
GaN Device

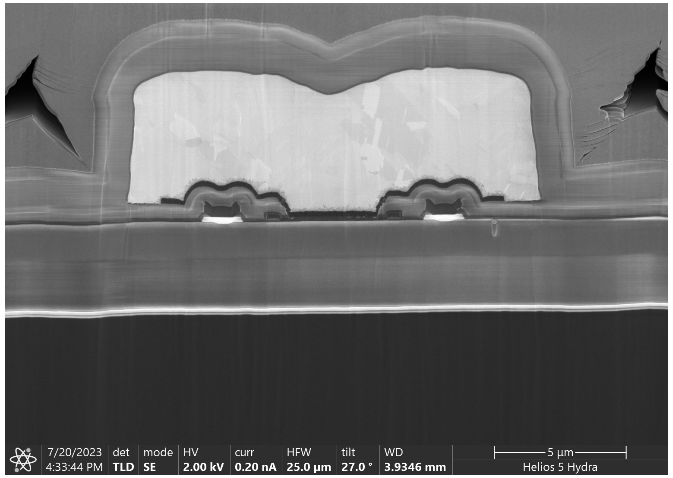
Xenon: 20m

Argon: 13m





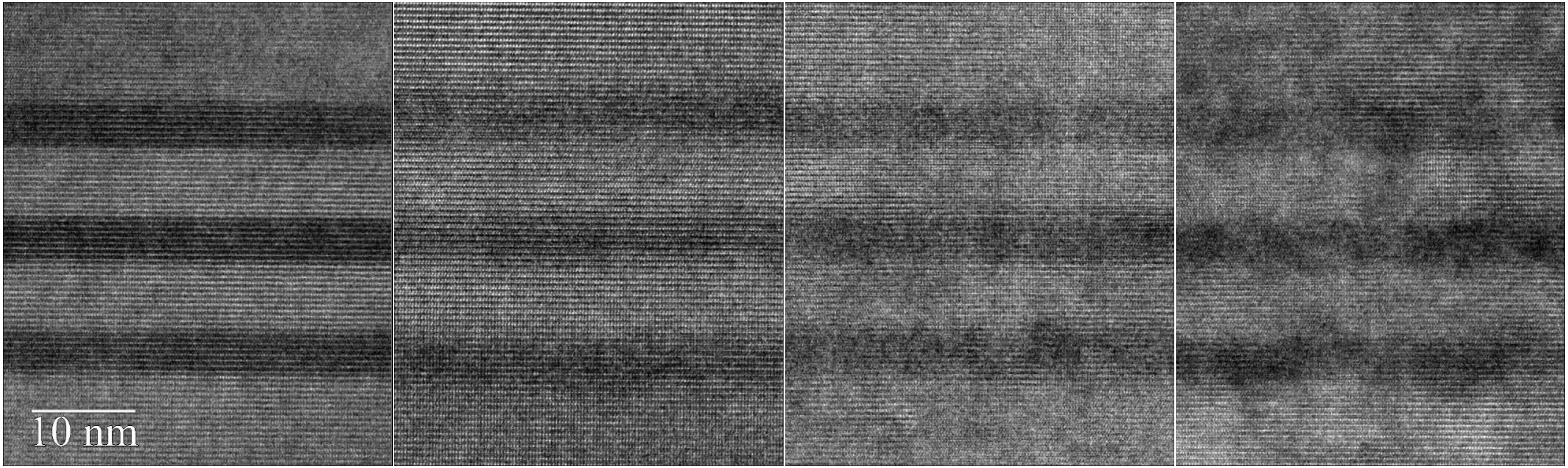




Argon ion is the winner: TEM images AlGaN/GaN

Helios 5 Hydra

Hydra Argon | **Helios Gallium** | **Hydra Xenon** | **Hydra Nitrogen**



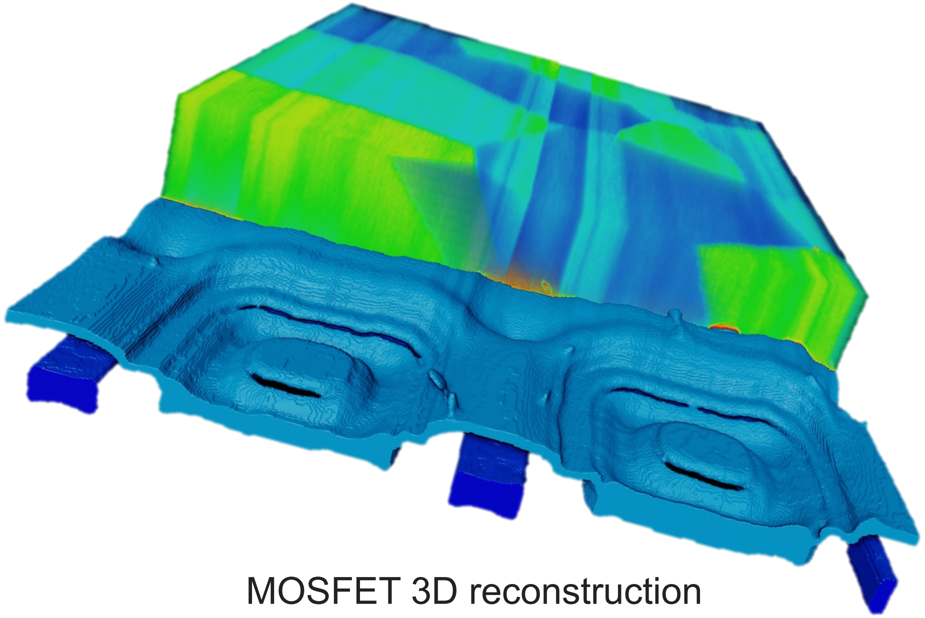
Ar+: clean interface AlGaN/GaN, **Ga+:** AlGaN/GaN layers might react with gallium; ***Xe+:*** gallium-free

N+: might forms nitrides

TEM microprobe images acquired by Talos F200X at 200 kV Ceta 16M camera, FIB final ion energy at 1 keV

FIB TEM sample preparation and Talos TEM images credit Shoji Sadayama and Hiromi Sekiguchi

Revolutionizing sample preparation quality with ion source technology



MOSFET 3D reconstruction utilized for defect identification

Introducing – Thermo Scientific™ Helios 5 Hydra

- Xe, N, Ar, O ion species (<10min switching time)
- AutoTEM 5 & Auto Slice and View 4 automated applications software
- Multiple gas precursor choices
- High max FIB current (Ar: 4.3μA)
- High performance, industry standard Helios SEM

Delayering

- Uses Xe^{+} ion beam and proprietary chemistry
- Automated & uniform delayering

Cross-sectioning

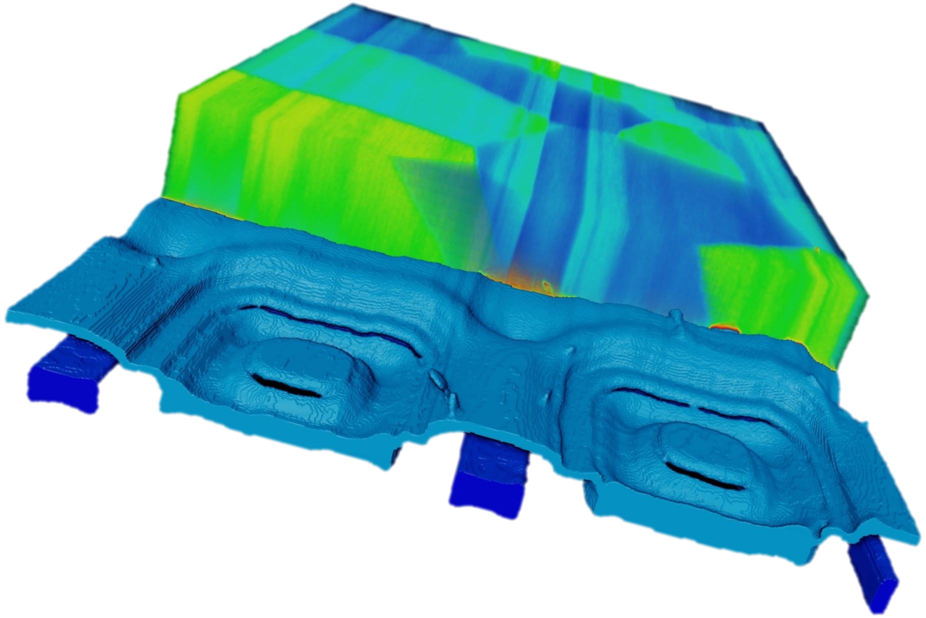
- Ar^{+} offers 2X milling throughput increase vs Xe^{+} (80X vs Ga^{+}) on most wideband gap materials

TEM sample prep

- Ar^{+} offers sample preparation without Ga^{+} artifacts

Novel ion sources provide application flexibility and performance benefits

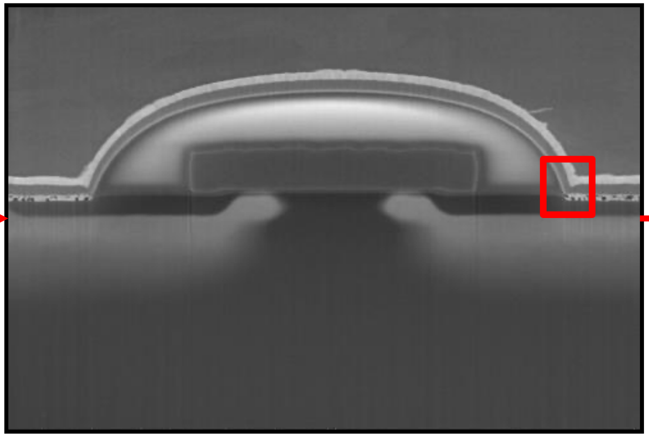
TEM Characterization & Analysis



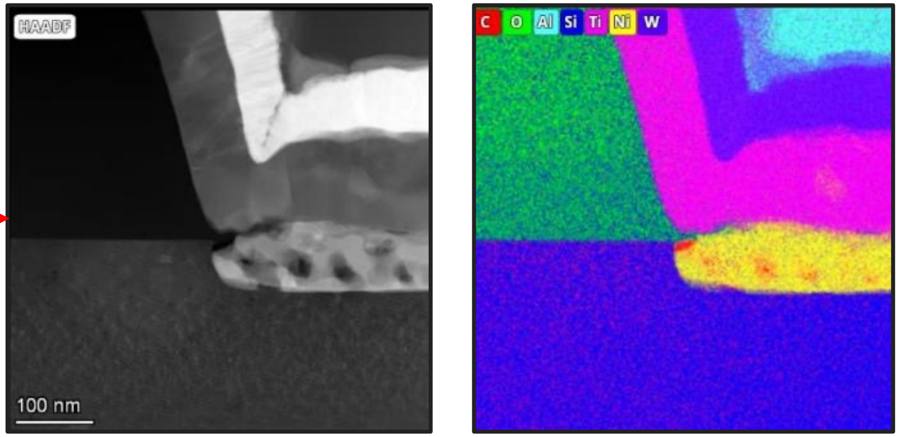
TEM Characterization & Analysis

- We have shown that defects can be localized and imaged using SEM …

Coarse Fault Localization → Sample Preparation → Fine Fault Localization → **Characterization and Analysis**



SEM

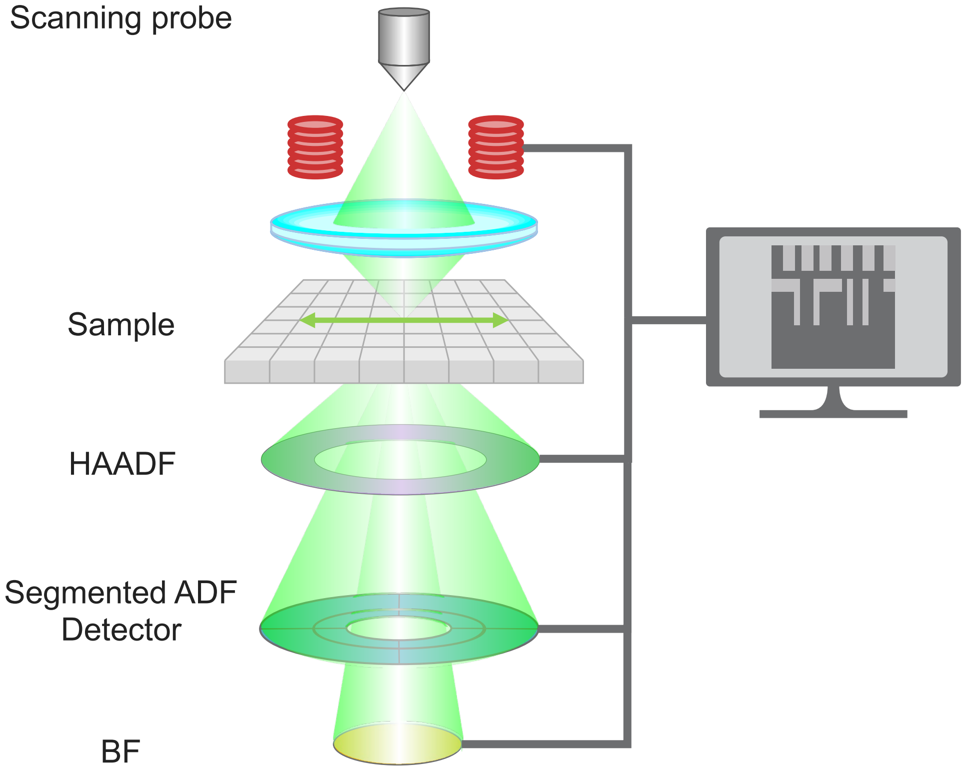


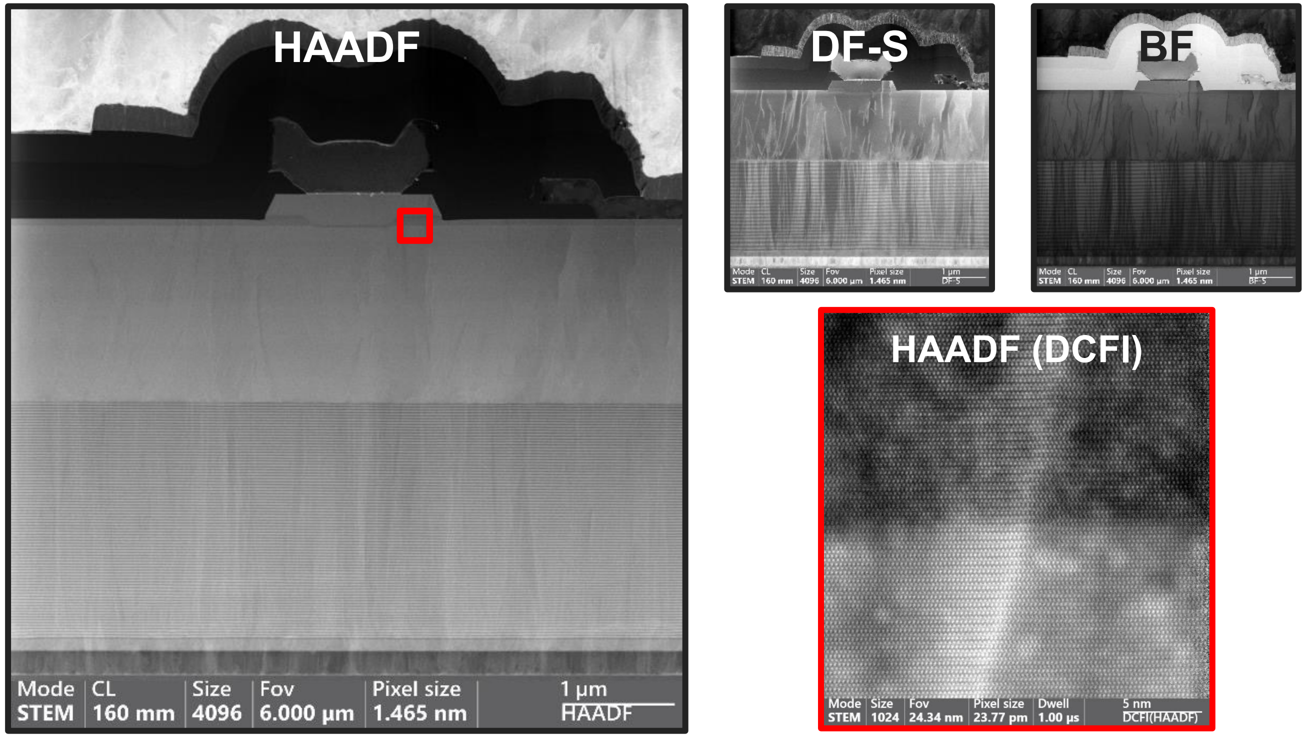
S/TEM

TEM characterization and analysis is also required

STEM applications: Imaging

Simultaneous STEM imaging // STEM resolution = 0.14 nm





Visualize contrast mechanisms with Panther STEM detection

STEM applications: Spectroscopy

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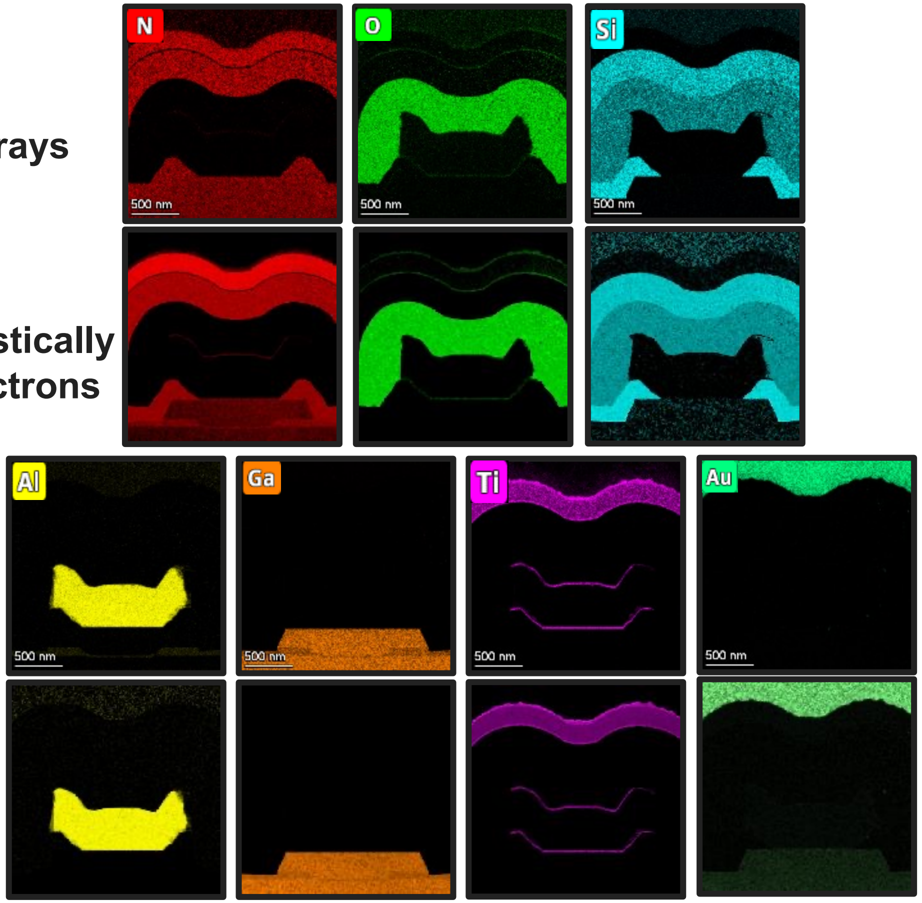
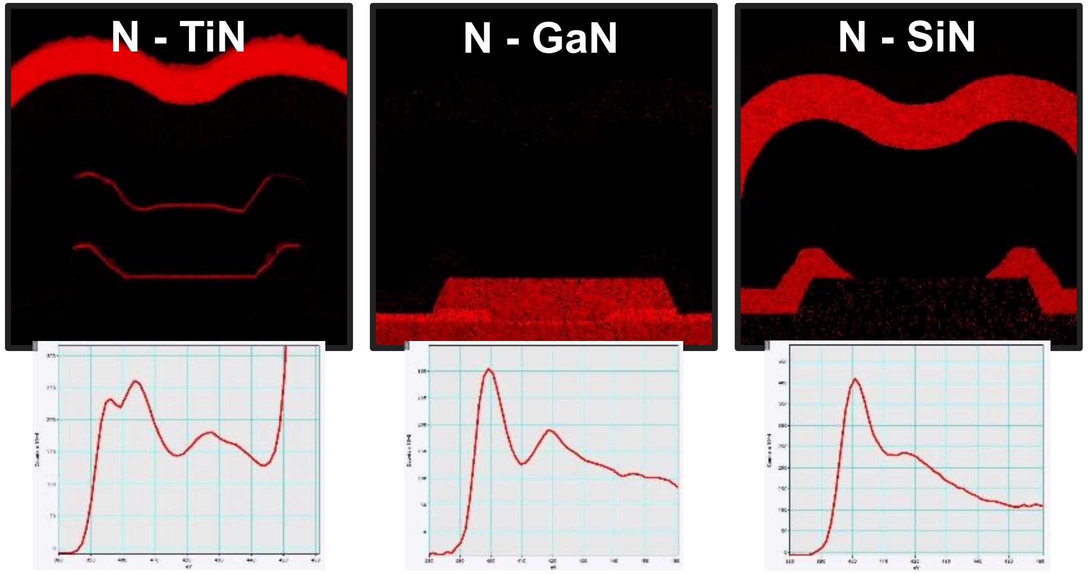
Energy Dispersive X-Ray Spectroscopy (EDS) // Electron Energy Loss Spectroscopy (EELS)

EDS
Detects x-rays

EELS
Detects inelastically scattered electrons



Nitrogen distribution (EELS)

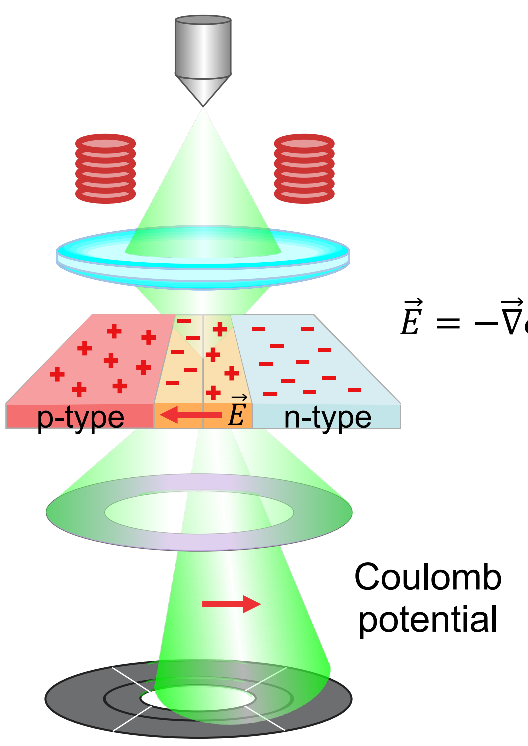


HT	Aperture	Probe Current	Dwell Time
200 kV	70 µm (C2)	300 pA	4.5 ms
Image Size	**Acquisition**	**Quantification**	**Filtering**
256 x 256 px	6 min	at%	None

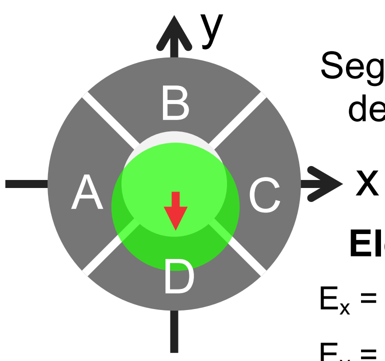
Simultaneous acquisition for heavy & light element detection with chemical bonding information

STEM applications: DPC/iDPC

P/N Junction



$$\vec{E} = -\vec{\nabla}\varphi \neq 0$$

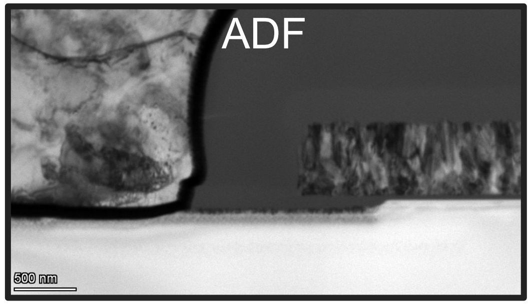


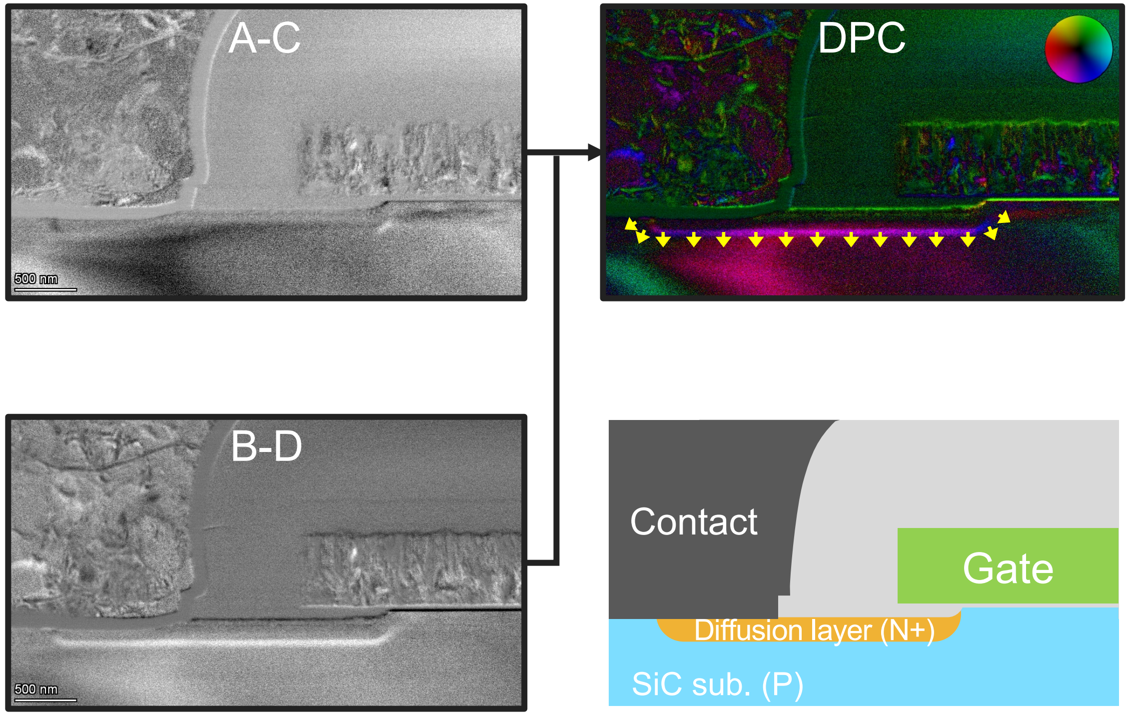
Segmented detector

Electric field

$E_x = -\partial V/\partial x = A - C$

$E_y = -\partial V/\partial y = B - D$

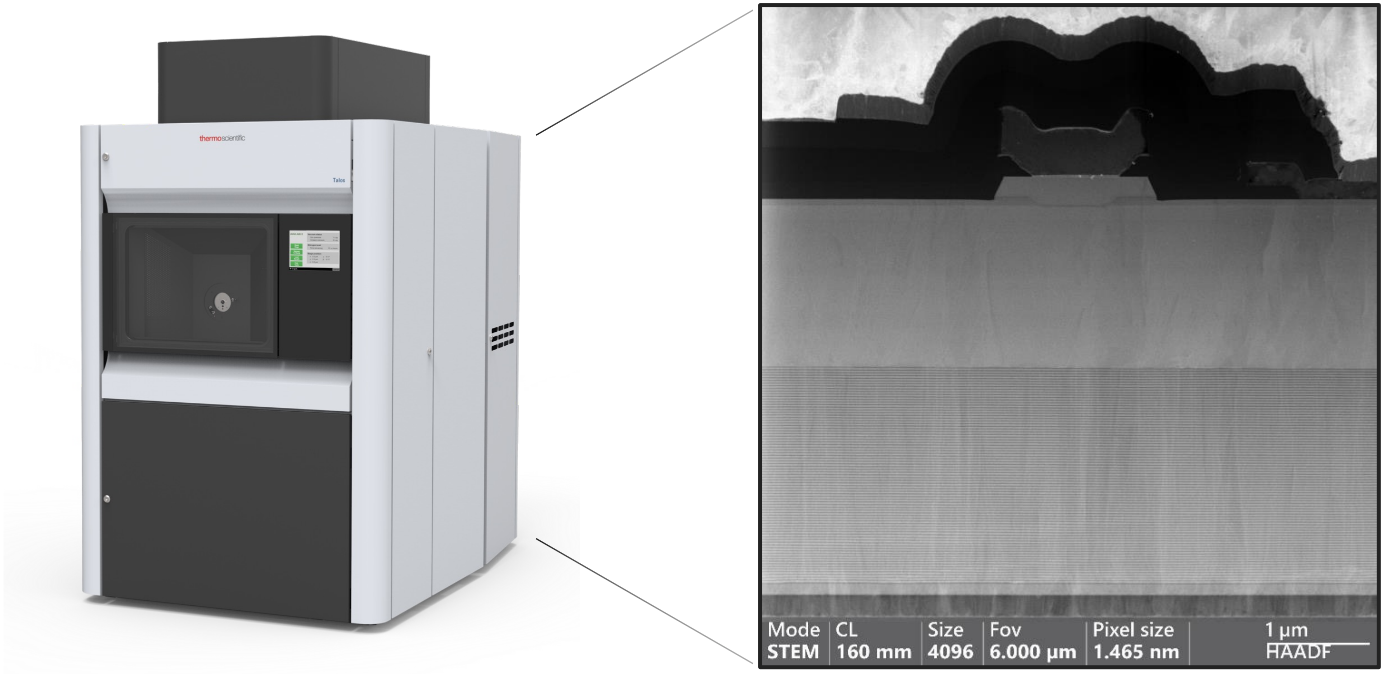




Images acquired by Nobuto Nakanishi, Thermo Fisher Scientific

DPC imaging provides access to in-plane electric fields via shifts in the center of the diffraction pattern

Talos F200E – the analytical TEM for power devices



Key Features

- Resolution 0.14 nm with X-CFEG (0.16 with X-FEG)
- Resolution with increased current → 1 nA = 0.19 nm
- Clean spectrum with Super-X (N, O, Al, Ga, In, Ni, Pt, Au)
- Simultaneous EDS/EELS capability
- Enhanced contrast with Panther STEM imaging
- 4kx4k STEM imaging for large FOV imaging of epi-stack
- Energy resolution 0.4 eV with X-CFEG
- 4D STEM strain analysis
- DPC/iDPC module

Fast time to data, flexible TEM designed to optimize quality of results & ease of use

The TEM of record at leading semiconductor analytical labs

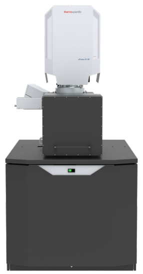
More than 650 Talos TEM systems installed worldwide

Conclusion

- Power devices with new materials introduce new failure analysis challenges
- Successful identification of complex defects may require multi-step and multi-tool workflows
- Ion species can provide application optimization and performance benefits
- A TEM is crucial and valuable for power semiconductor pathfinding and device development
- Thermo Fisher Scientific offers a total workflow solution for power device analysis

Coarse Fault Localization → Sample Preparation → Fine Fault Localization → Characterization and Analysis

Elite
Lock-In Thermography



nProber IV
SEM or AFM –based nanoprobing

Talos
(S)TEM imaging & EDS

Hydra
FIB cross-section & delayering, SEM analysis

Meridian
Optical fault isolation

Thank you

Antonio Mani – antonio.mani@thermofisher.com

Questions?

Antonio Mani – antonio.mani@thermofisher.com