EMPAD G2

Integrated direct detection 4D STEM

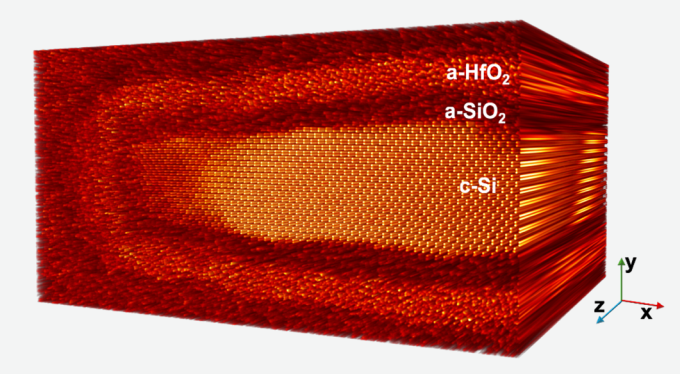

Figure 1: Buried defects and rough interfaces in a transistor structure identified in 3D using multi slice electron ptychography.[1]

The Thermo Scientific™ Electron Microscope Pixel Array Detector (EMPAD) G2 enhances the capabilities of four-dimensional scanning transmission electron microscopy (4D STEM) by sampling the diffraction plane at each image point.

This detailed sampling unlocks new analysis capabilities, including:

- **Strain analysis:** Strain within the material can be quantified by measuring the relative shifts of diffraction spots. Strain analysis is crucial for improving material performance and nanodevice functionality.
- **Orientation mapping:** The orientation of crystal structures can be determined from diffraction pattern maps. This helps in predicting and enhancing material properties, which is essential for material development.
- **Electric and magnetic field analysis:** Center-of-mass analysis of diffraction patterns shows beam deflection from local fields, providing insights into electric and magnetic fields within the sample. This is vital for developing electronic and magnetic devices.
- **Resolution enhancement:** Ptychography methods enhance image resolution, capturing fine details for more accurate and comprehensive analyses, which is essential for advanced research. An example of MEP is shown in Figure 1.

Key benefits
Boost lab efficiency with better integration: All analysis modalities, including 4D STEM, are controlled in Thermo Scientific™ Velox™ Software.
High sensitivity gives high data quality: The EMPAD G2 offers high detective quantum efficiency at all beam energies.
Address more sample types with higher frame rate: Operates at up to 10 kHz at full resolution and bit-depth, reduces acquisition time for typical 128 × 128 maps from as long as 30 minutes to under two seconds.
Capture high-quality diffraction data with the EMPAD G2's high dynamic range: 10^7:1: Detect both single electrons and high electron beam currents >180 pA per pixel at 300 kV and 900 pA at 60 kV. Linear response over the large dynamic range helps ensure quantitative diffraction data collection.
High signal-to-noise ratio for high-quality data: Achieves high SNR across a wide range of conditions, essential for precise measurements.
Reduce specimen damage with high tension flexibility: Utilizes a pixel design with a 150 µm pixel pitch, optimized for high-energy electrons, which works well over the full HT range of the TEM from 30 to 300 keV. HT can be optimized to minimize specimen damage. Choose your HT for your sample, not your detector.
High-quality data and reduced specimen damage with continuous imaging: Near-unity duty cycle allows for continuous signal acquisition even during readout, wasting no electrons.
Low operator learning bias: Velox Software's intuitive workflow gives you control of all analysis modalities in one place. Built-in virtual detectors offer versatile data analysis.
Comprehensive support: Benefit from Thermo Fisher Scientific's global network of experts and dedicated customer service.

The 4D STEM approach goes beyond traditional methods that only count the number of electrons per scan point, offering additional flexibility to extract information from TEM specimens.

Integrated software

With the EMPAD G2, 4D STEM becomes integral to the TEM ecosystem. Velox Software acquires 4D STEM data alongside STEM imaging and EDX mapping data, making 4D STEM accessible without advanced training or new software. The software provides a live view of diffraction patterns to help optimize imaging parameters and focus. The resulting 4D STEM data can then be processed offline, with export options for advanced processing.

During high-speed acquisition, the Thermo Scientific scan engine delivers the same field of view for STEM, 4D STEM, and EDX. Metadata ensures all data is correctly calibrated with other TEM modalities.

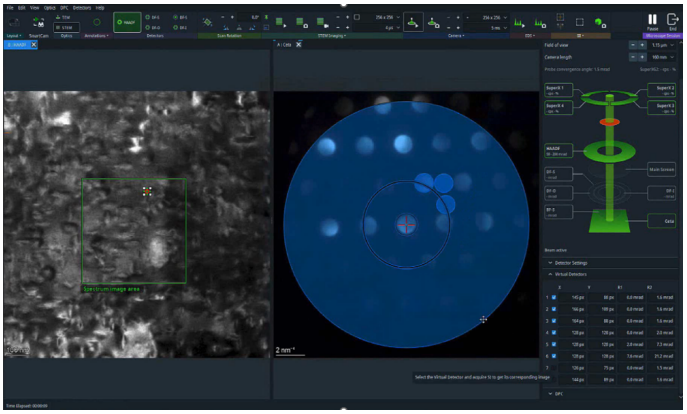

Figure 2. Screenshot of 4D STEM experiment in Velox Software with various virtual detectors during a live acquisition.

High-tension, flexible, robust design

The EMPAD G2 is radiation hard up to 300 keV and can operate as low as 30 kV. The HT can be optimized toward the sample type rather than to the detector. Its large physical pixel size helps ensure excellent image quality, even at high kV.

The robust design delivers long-term operation. The EMPAD G2 performs reliably on Thermo Scientific TEM platforms, and the EMPAD G2 is compatible with all Thermo Scientific™ Spectra™ Cameras. EMPAD G2 supports Thermo Scientific™ AutoScript™ Software, enabling customized 4D STEM workflows.

Figure 3: Image of the EMPAD G2 including housing, retraction mechanism, and sensor unit.

Optimized detector design

The EMPAD G2 is designed for optimal maximum usable imaging speed (MUIS),[2] which determines the optimal speed at which a detector can operate to achieve a desired signal-to-noise ratio. The MUIS metric considers factors such as electron arrival rates, detector saturation, and pixel count, providing a guideline for optimizing detector design by matching source and detector capabilities for various imaging applications. In 4D STEM, speed and pixel count alone do not guarantee better data. Precision depends on the dose recorded and the quality of the signal in each pixel, while very large pixel arrays can create datasets that are harder to manage. The EMPAD G2 balances sensitivity, high saturation, dynamic range, and practical data volume to support high-quality quantitative diffraction data across demanding electron microscopy applications.

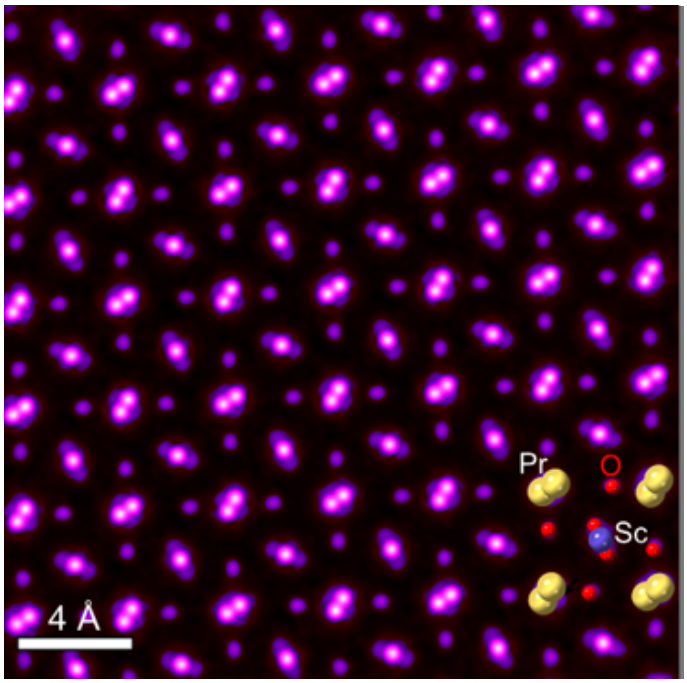

Figure 4. Ptychography reconstruction from $PrScO_3$ showing super resolution of 16pm, which is significantly higher than the optical limit of the TEM.[3]

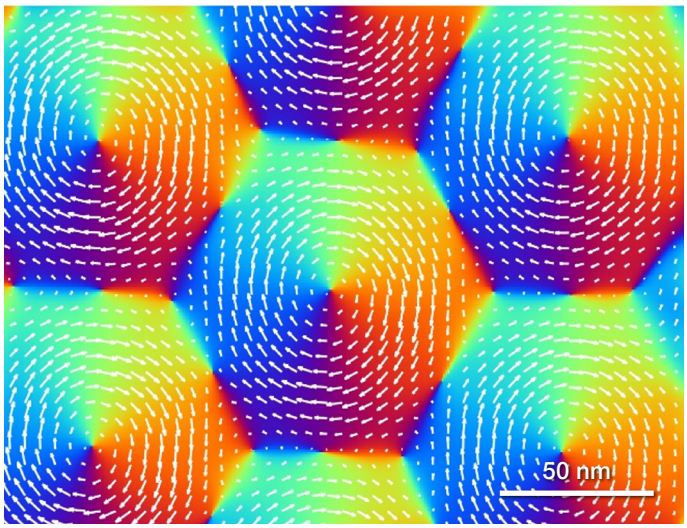

Figure 5: Lorentz ptychography of magnetic skyrmions in FeGeat 100K recorded with EMPAD G2. *Image courtesy of Zhen Chen and David Muller, Cornell University.*[4]

EMPAD G2 detector specifications

Sensor dimensions	
Active area	• 19.2 × 19.2 mm or • 38.4 × 38.4 mm
Pixels	• Single 128 × 128 or • Quad 256 × 256
Pixel size	• 150 µm x 150 µm
Active thickness	• 500 µm
Performance	
DQE(0)	• 0.96 at 60 kV • 0.95 at 80 kV • 0.94 at 200kV • 0.94 at 300 kV
Dynamic range	• 10^7:1 across all exposure times
Maximum current per pixel	• 180 pA at 300 kV • 270 at 200 kV • 900 pA at 60 kV
Signal-to-noise ratio	• 75:1 at 300 kV • 50:1 at 200 kV for a single electron
High-tension range	• 30 to 300 keV
Maximum speed	
10,000 fps at full well capacity	

Storage capacity
• **Internal storage:** 6 TB (standard), additional 24 TB (option)
Control and imaging software
• **Control software:** Velox Software
• **Live view:** Continuous acquisition of diffraction patterns to support focusing and live optimization
• **Synchronized acquisition:** High-speed 4D STEM acquisition in Velox Software, including virtual detectors with live feedback
• ***In situ* recording:** Series acquisition for observing specimen and crystal-structure changes over time
• **Offline processing:** Offline reprocessing of 4D STEM data stacks in Velox Software, with export options for advanced processing
• **Multimodal acquisition:** Simultaneous 4D STEM and EDX acquisition
• **Scripting:** 4D STEM integration into customized workflows using scripting support in AutoScript Software
• **Metadata:** Enhanced data connectivity to support faster publication workflows
System requirements
Windows 11, Timeos, and Thermo Scientific™ Talos™ TEM, Spectra™ (S)TEM, Iliad™ (S)TEM, and Metrios™ TEM
Retrofit
For retrofit availability, contact your local sales and service organization

1. Karapetyan S, Zeltmann SE, Wilk G, Chen T-K, Hou VD-H, Muller DA (2025) **arXiv**: https://doi.org/10.48550/arXiv.2507.07265
2. Hugh Philipp MT, Tate MW, Shanks KS, Mele L, Peemen M, Dona P, *et al.* **Microscopy and Microanalysis** 2022, 28, 425–440.
3. Chen Z, Jiang Y, Shao YT, Holtz ME, Odstrcil M, Guizar-Sicairos M, *et al.* **Science** 2021, 372, 826–31.
4. Chen Z, Turgut E, Jiang Y, Nguyen KX, Stolt MJ, Jin S, *et al.* **Nat. Nanotechnol.** 2022, 17, 1165–70.

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Notes

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