Advancing nanoscale characterization of semiconductor devices by effortless 4D-STEM workflows

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TESCAN ORSAY HOLDING

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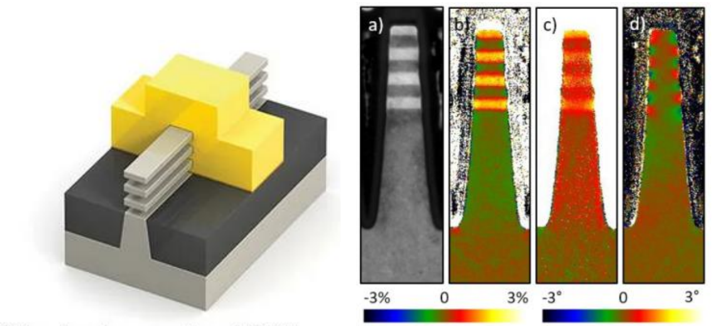
Presentation Outline

- Motivation and introduction of 4D-STEM analytical techniques
- Improving accuracy of diffraction measurements with beam precession
- Strain analysis and orientation mapping using 4D-STEM measurements
- Improving sensitivity of phase/orientation mapping with multimodal analysis
- Characterization of a semiconductor device by 4D-STEM measurements
- Effortless 4D-STEM measurements provided by state-of-the-art technology and automation

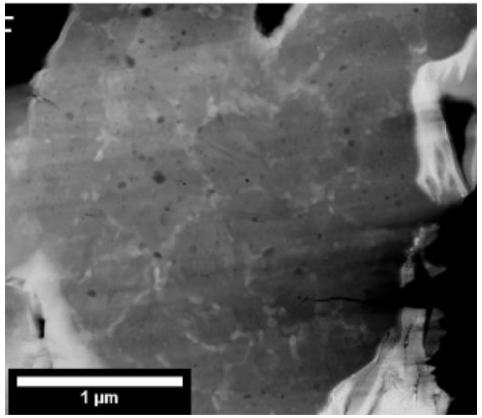
Drivers for Nanoscale Characterization

- Development of new and improved nanostructures and devices
- Material properties given by both composition and structure
- Grain size and distribution affected by production process
- Strain engineering and failure analysis in semicon devices

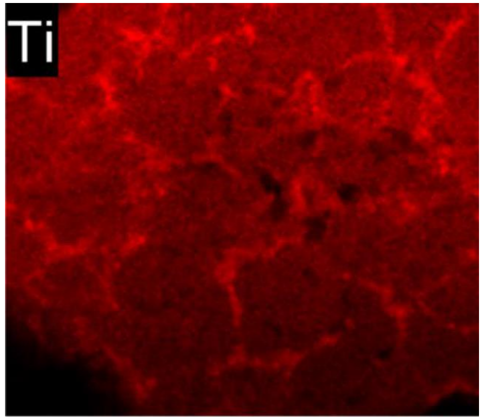


Li et al. (2019): 10.1017/S1431927619010821

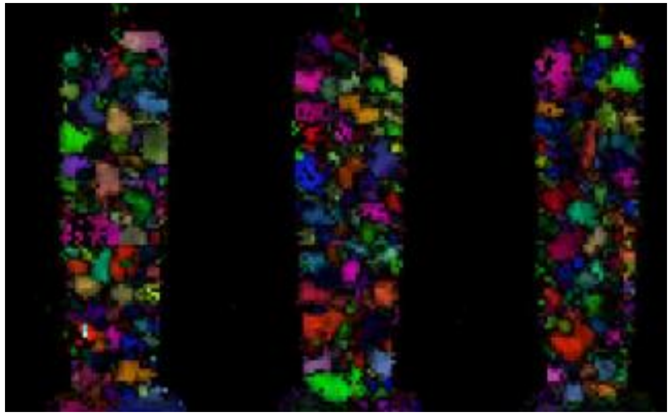
Strain measurements



Nanoscale imaging



Compositional analysis

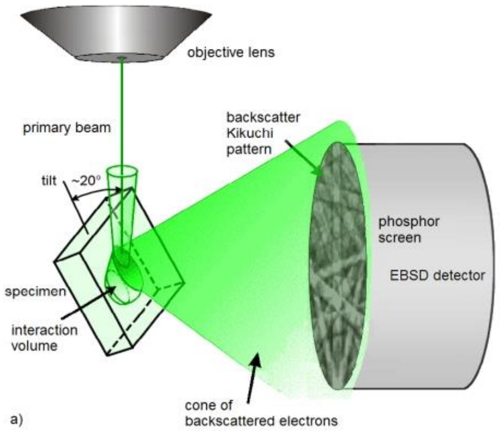


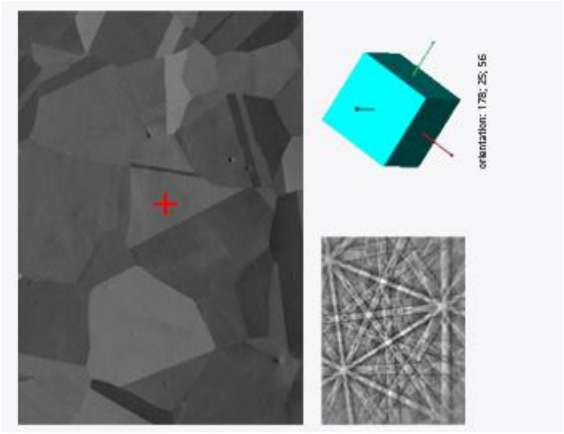
Grain size and orientation

Traditional Techniques for Phase and Orientation Analysis

Electron Backscatter Diffraction (EBSD)

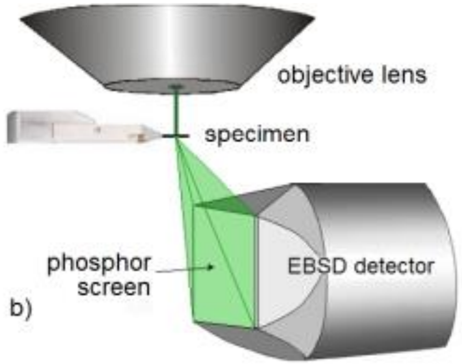
- Employs Kikuchi lines from back scattered electrons
- Specimen must be tilted, requires large probe current
- High angular resolution and large FOV possible
- Spatial resolution is limited to 25-100 nm

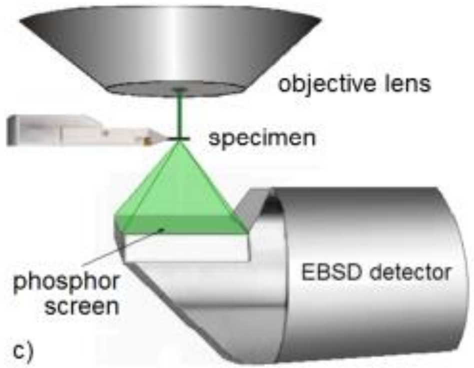




Transmission Kikuchi Diffraction (TKD)

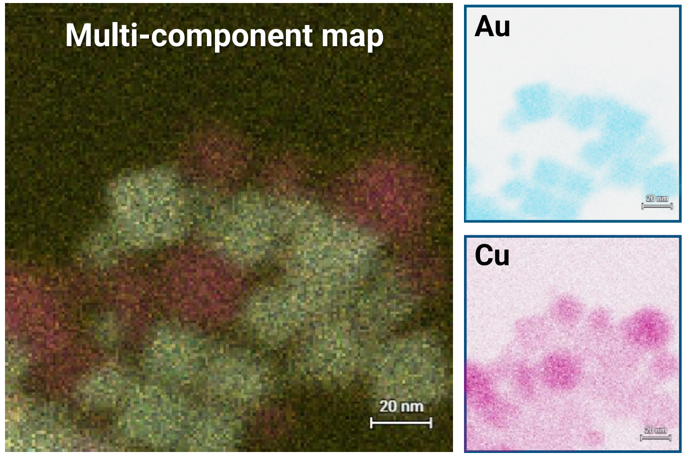
- Employs Kikuchi lines from transmitted electrons
- Specimen is not tilted, smaller working distance
- Requires very thin specimen (transparent at 30 kV)
- Spatial resolution is improved to 5-10 nm

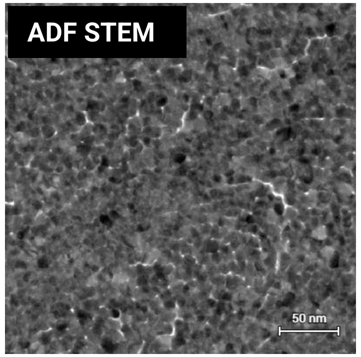


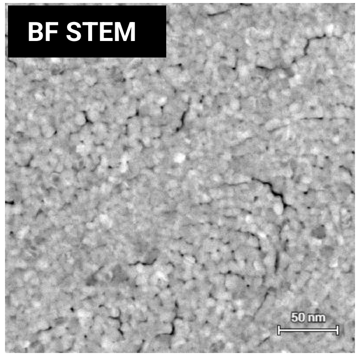


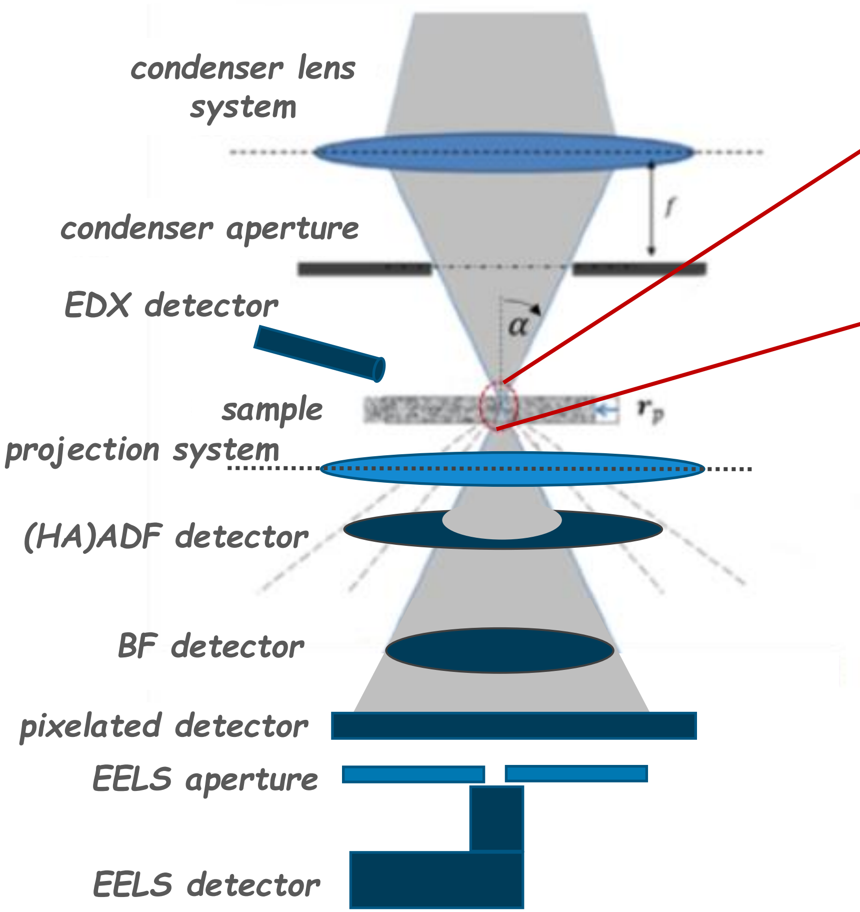
Analytical Scanning Transmission Electron Microscopy

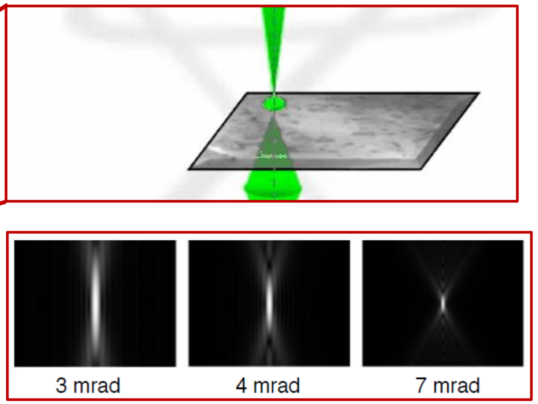
Breaking to <5 nm resolution range

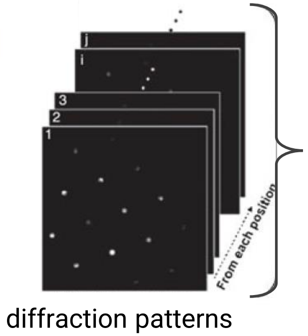












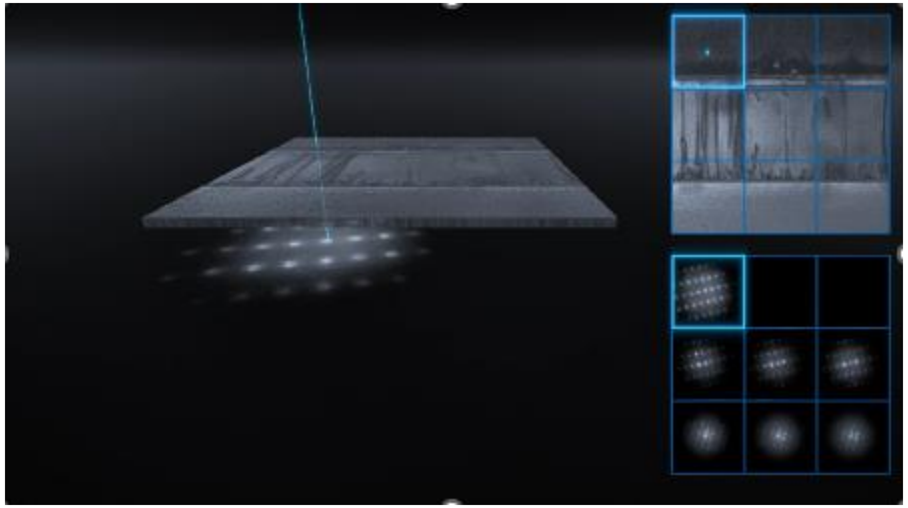
Structural information

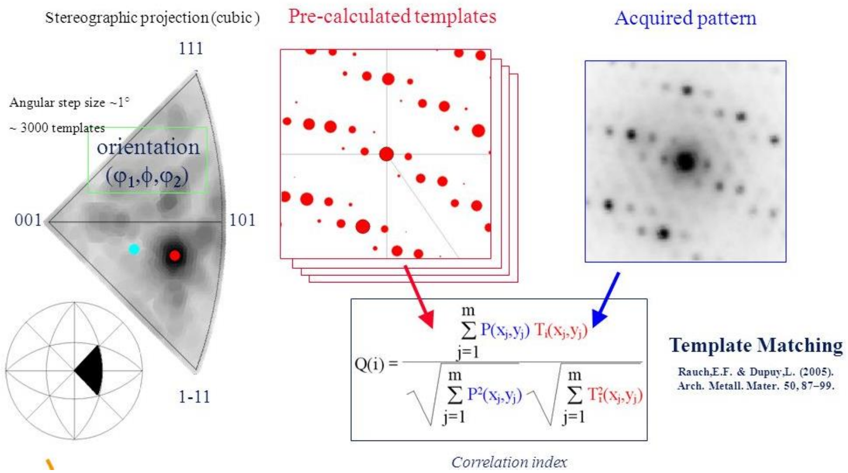
- Phase mapping
- Orientation measurements
- Strain measurements
- Electric field measurements
- Structure determination

Phase and Orientation Analysis using 4D-STEM

Automated crystallographic orientation mapping

- Employs NBED of transmitted electrons
- Specimen is not specifically tilted
- High angular resolution and large FOV possible
- Spatial resolution 1-4 nm when using FEG STEM
- Template matching of experimental diffraction patterns
- Requires known structural file(s) for template generation
- Improvement of template matching with beam precession (typically using the ASTAR module from NanoMEGAS)





Sources: Nanomegas.com
Rauch E. et al. (2005): 10.1002/mawe.200500923

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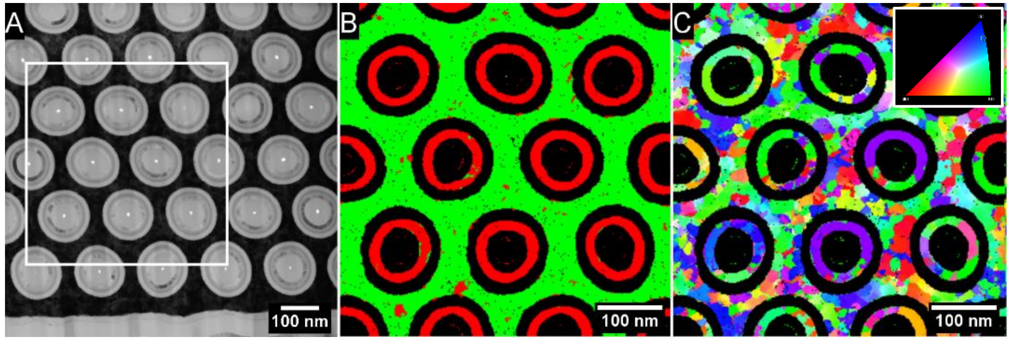
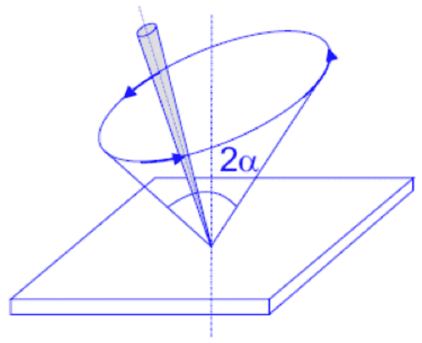


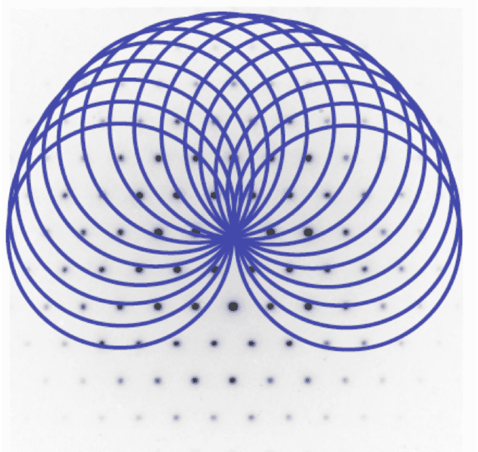
Phase and orientation analysis of 3D-NAND devices

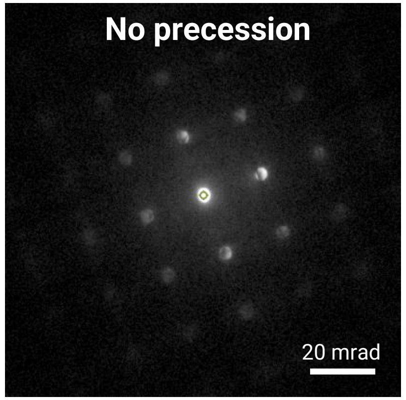
Sources: Nanomegas.com
Rauch E. et al. (2005): 10.1002/mawe.200500923

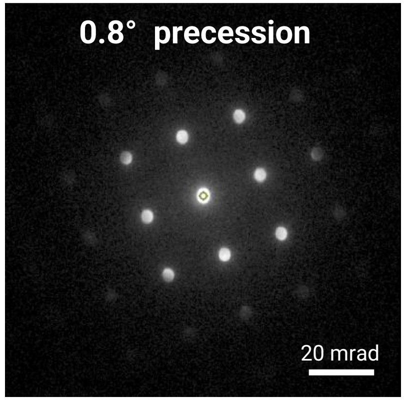
INCREASING ACCURACY BY BEAM PRECESSION



Precession Microdiffraction



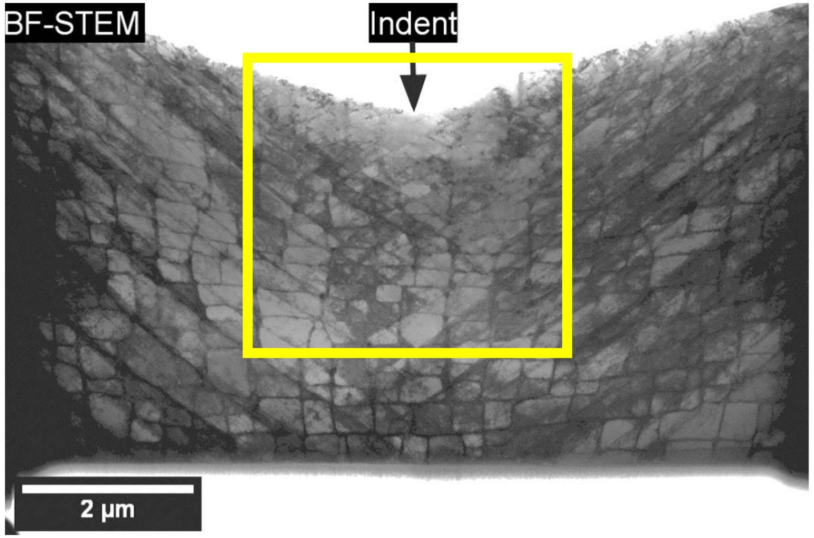




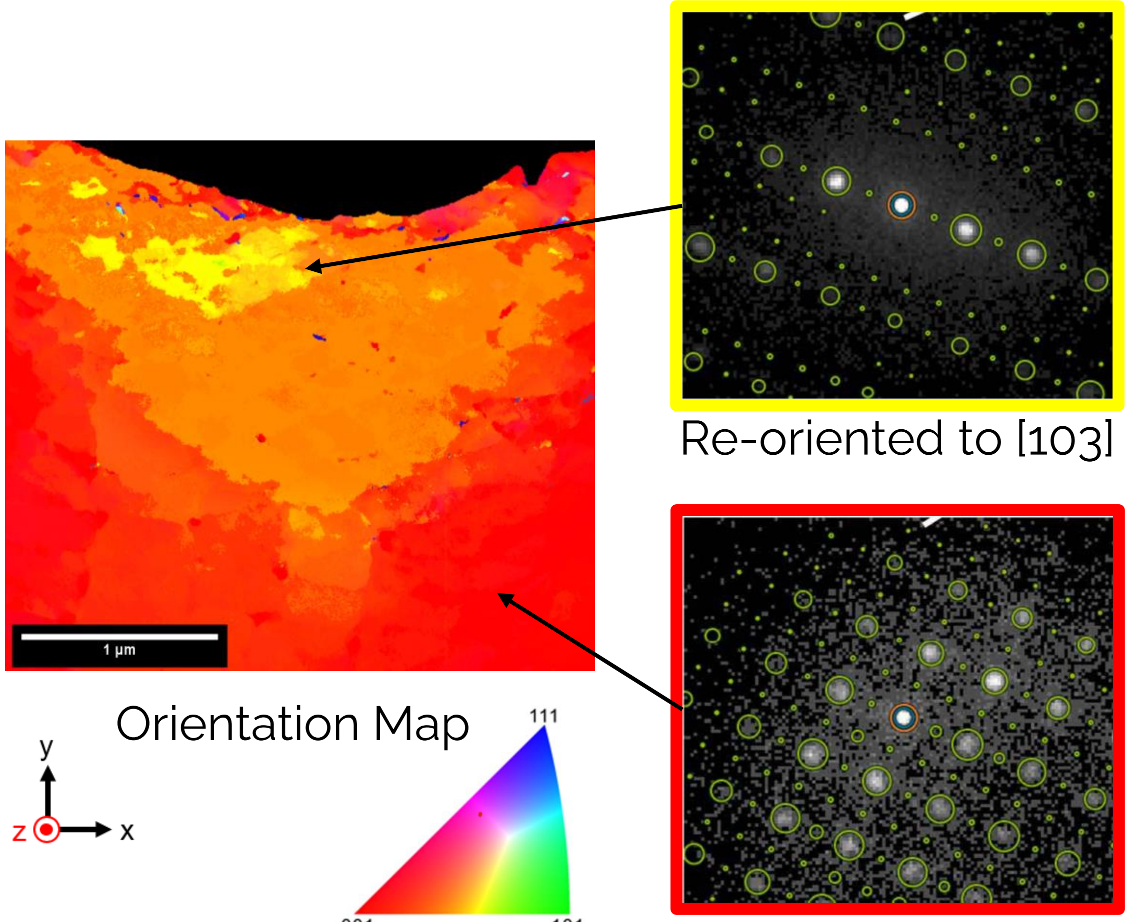
- Intensity within spots is more homogeneous and Kikuchi lines are averaged out
- Higher order Bragg spots are excited and observed in diffraction patterns
- Observed spot intensities correspond better to kinematical intensities

Orientation and Strain Mapping with Beam Precession

Deformation behavior in Ni-based superalloys



STEM BF Image



Orientation Map

Re-oriented to [103]

Undeformed [001]

Benefits of Beam Precession

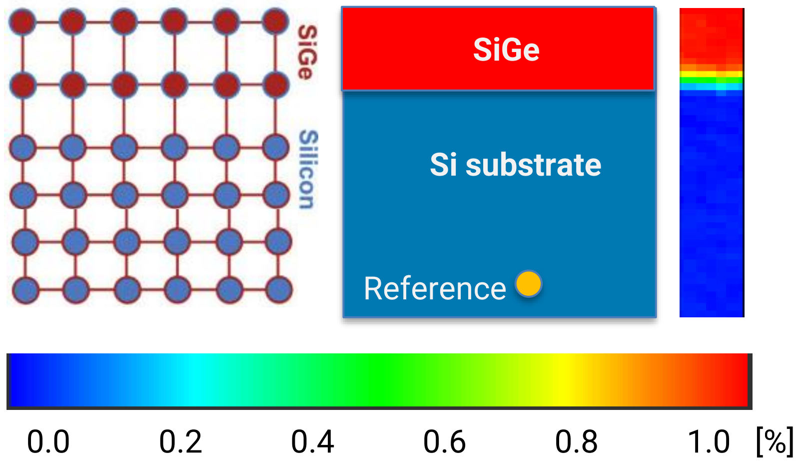
- **Orientation mapping**
  - Higher resolution spots enable a higher angular resolution
  - Better matching of kinematical templates with acquired data

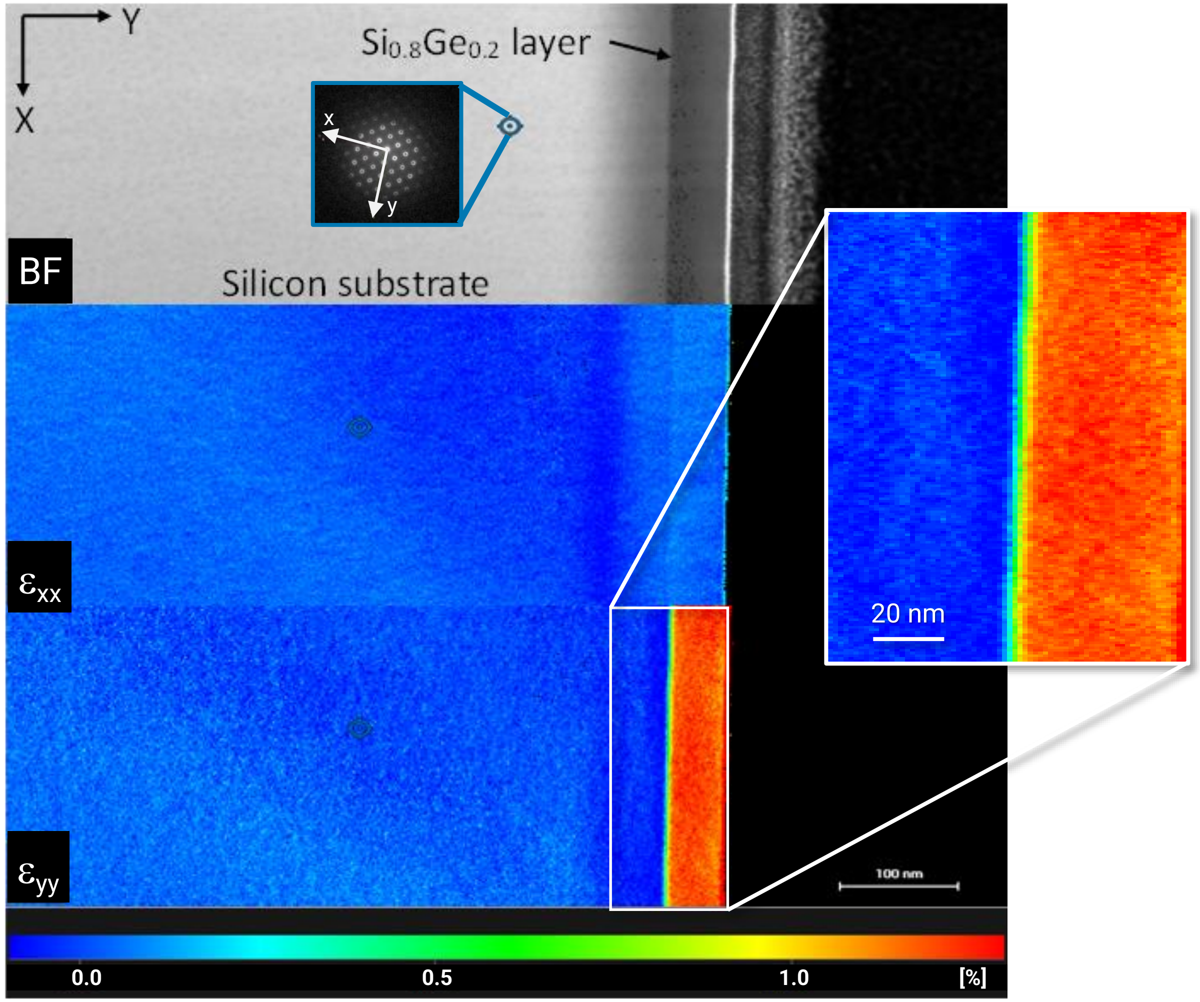
- **Strain mapping**
  - Higher resolution spots are more sensitive to strain and improve strain precision
  - Better identification of spots and their central positions improves strain precision

- **Implications for non-ideal specimen**
  - Results are less sensitive to the thickness variations (uneven specimen)
  - Results are less sensitive to slight misorientation from the zone axis (bent specimen)

Strain Measurement using NBED with Beam Precession

- Strain between different crystal lattices
- Strain engineering and failure analysis
- Direct measurement of diff. spot displacement
- 2-4 nm spatial resolution (using FEG STEM)
- High precision with beam precession

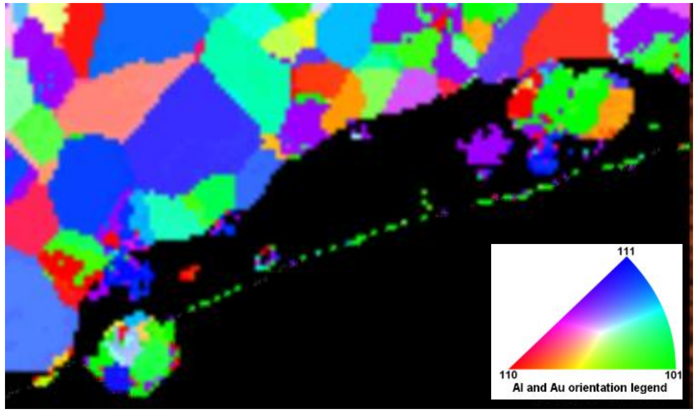




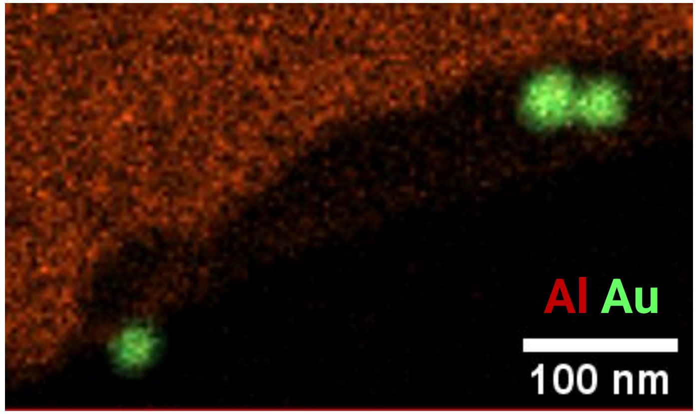
Improving Accuracy of Phase Mapping with EDS

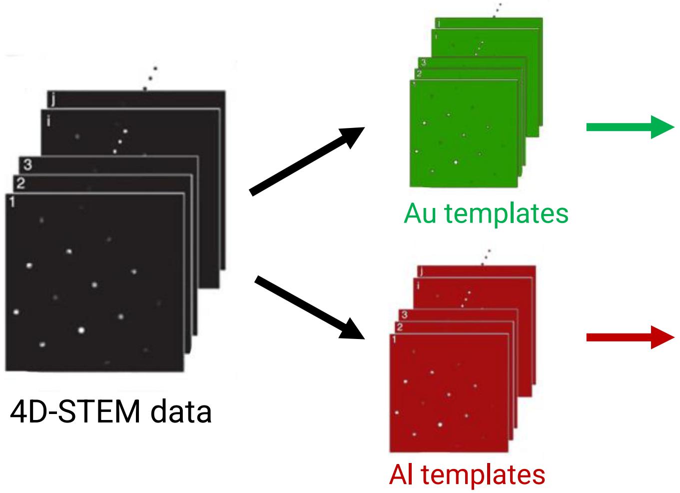
Analysis of phases with lattice parameter difference <5%

4D-STEM orientation mapping (Au, Al)

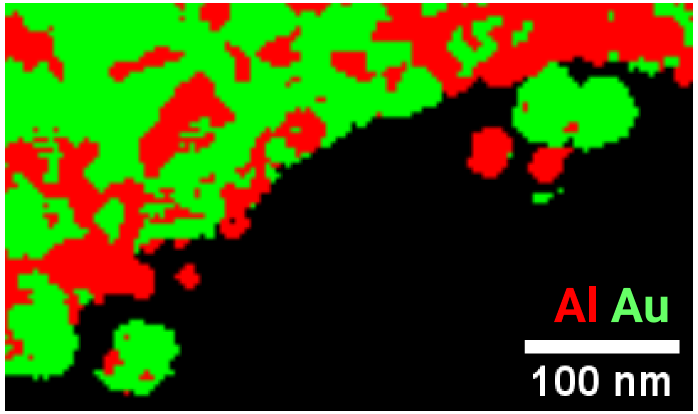


EDS elemental map





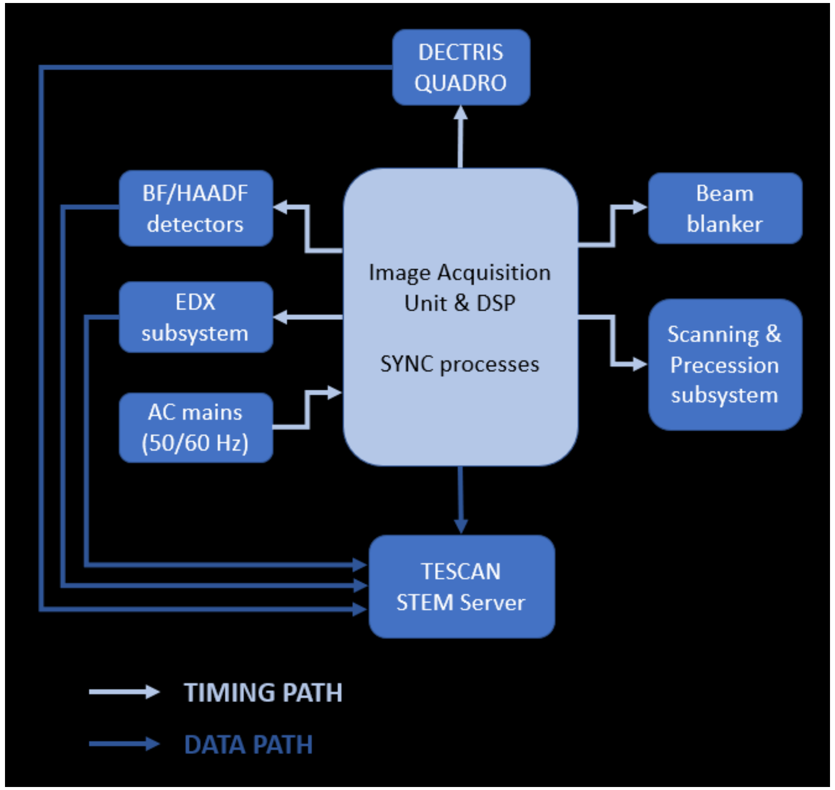
4D-STEM phase map



Improving Accuracy of Phase Mapping with EDS

Analysis of phases with lattice parameter difference <5%

Synchronization of multimodal data readout



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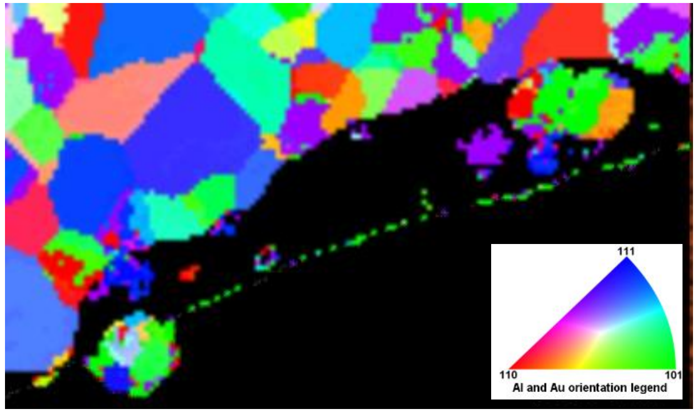

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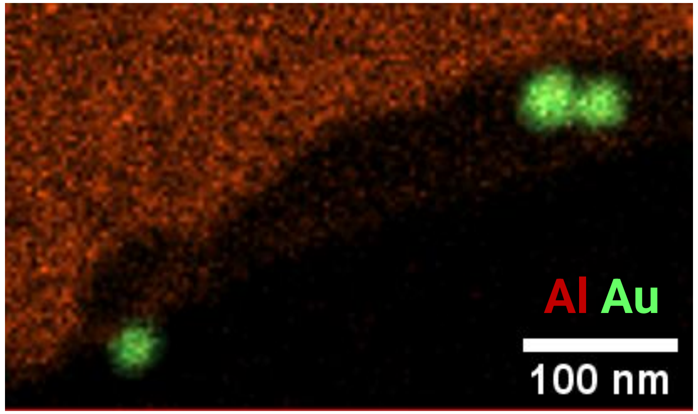
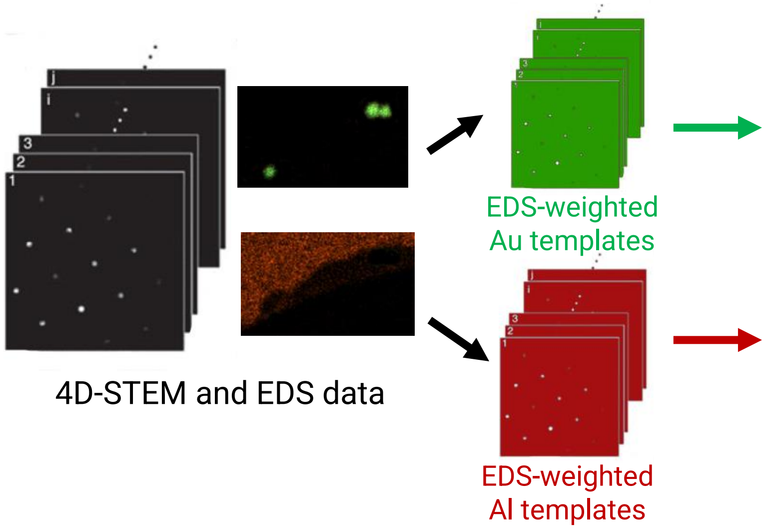
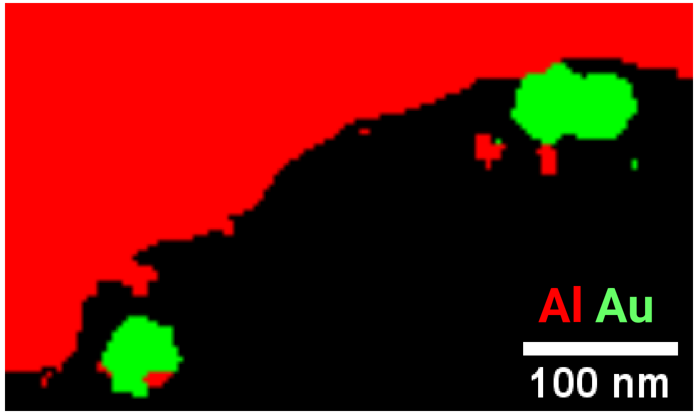
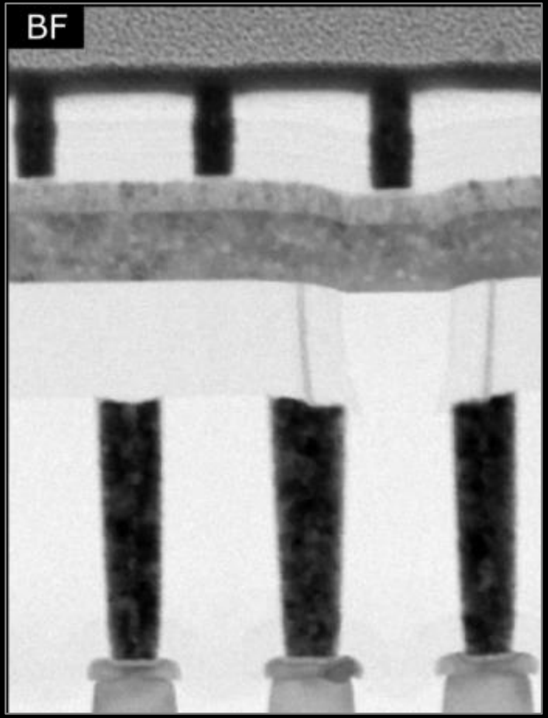




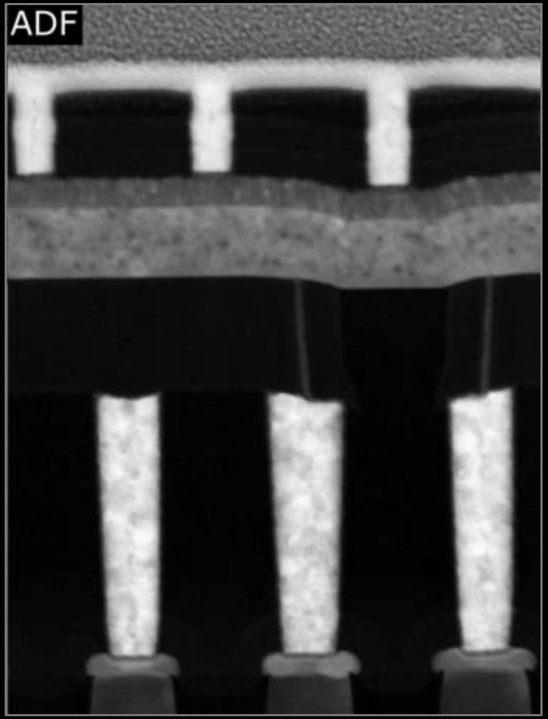
4D-STEM w/EDS phase mapping



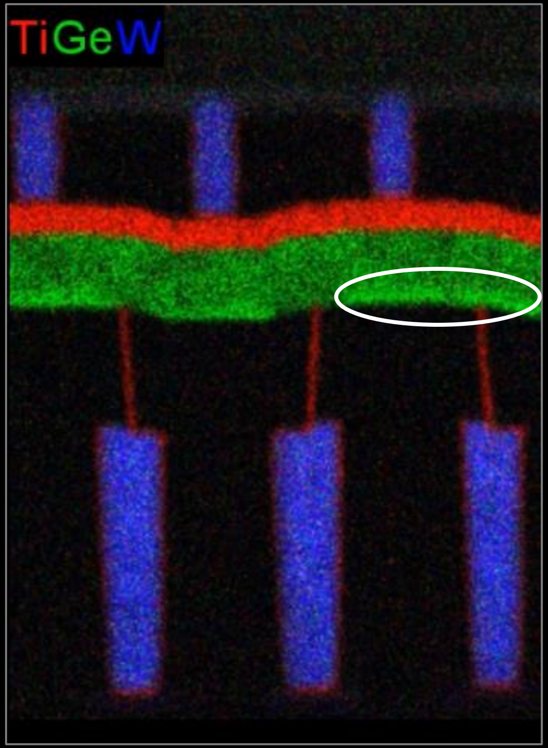
Characterization of a Semiconductor Device



BF imaging



DF imaging



EDS mapping

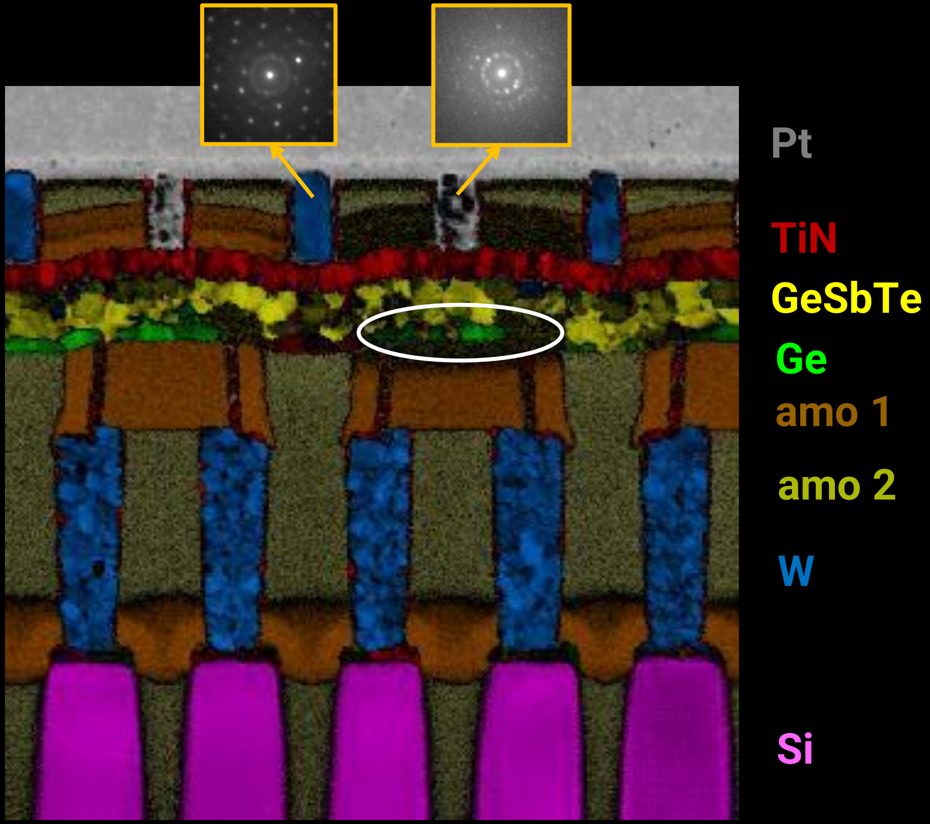
CHARACTERIZATION OF A SEMICONDUCTOR DEVICE

4D-STEM measurement

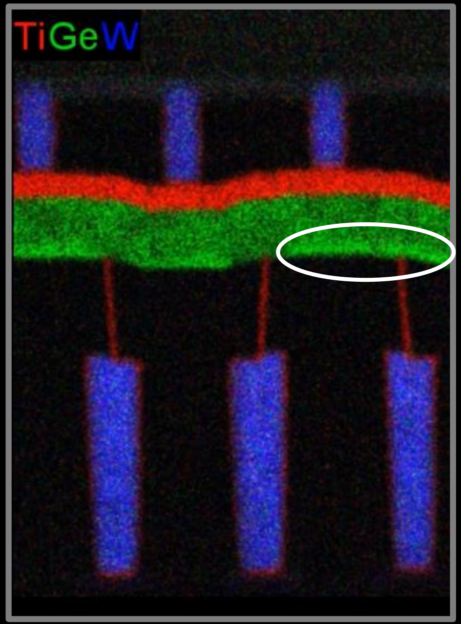
- probe size: 1.15 nm
- conv. angle: 2 mrad
- precession: 0.8°
- pixel size: 2.0 nm
- diff. size: 120 mrad

4D-STEM analysis

- 5 cubic templates
- 3 amorphous templates
- Postprocessing in ACOM
- 12 mins using 7 cores



4D-STEM phase mapping



EDS mapping

A STEM THAT IS AS EASY TO USE AS A SEM

“I am proud of our group, in Brno and Tempe.“

We have taken a very complicated instrument and turned it into something that anyone can use. It is a great example of expert systems automation and user experience design.

JK Weiss,

Applications Development Manager

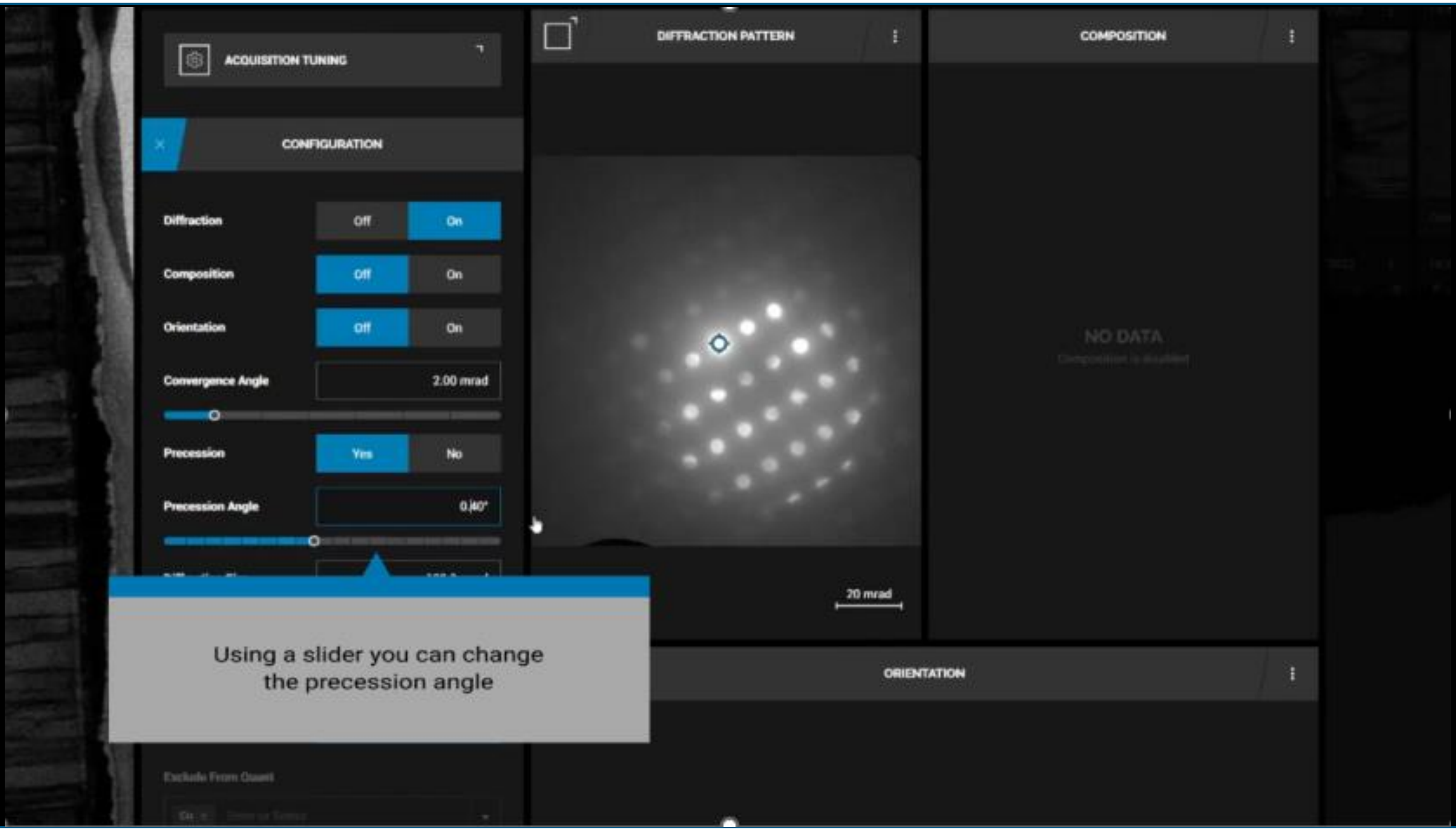
and General Manager of TESCAN Tempe

A STEM THAT IS AS EASY TO USE AS A SEM

A contemporary 4D-STEM setup

TESCAN TENSOR integrated solution

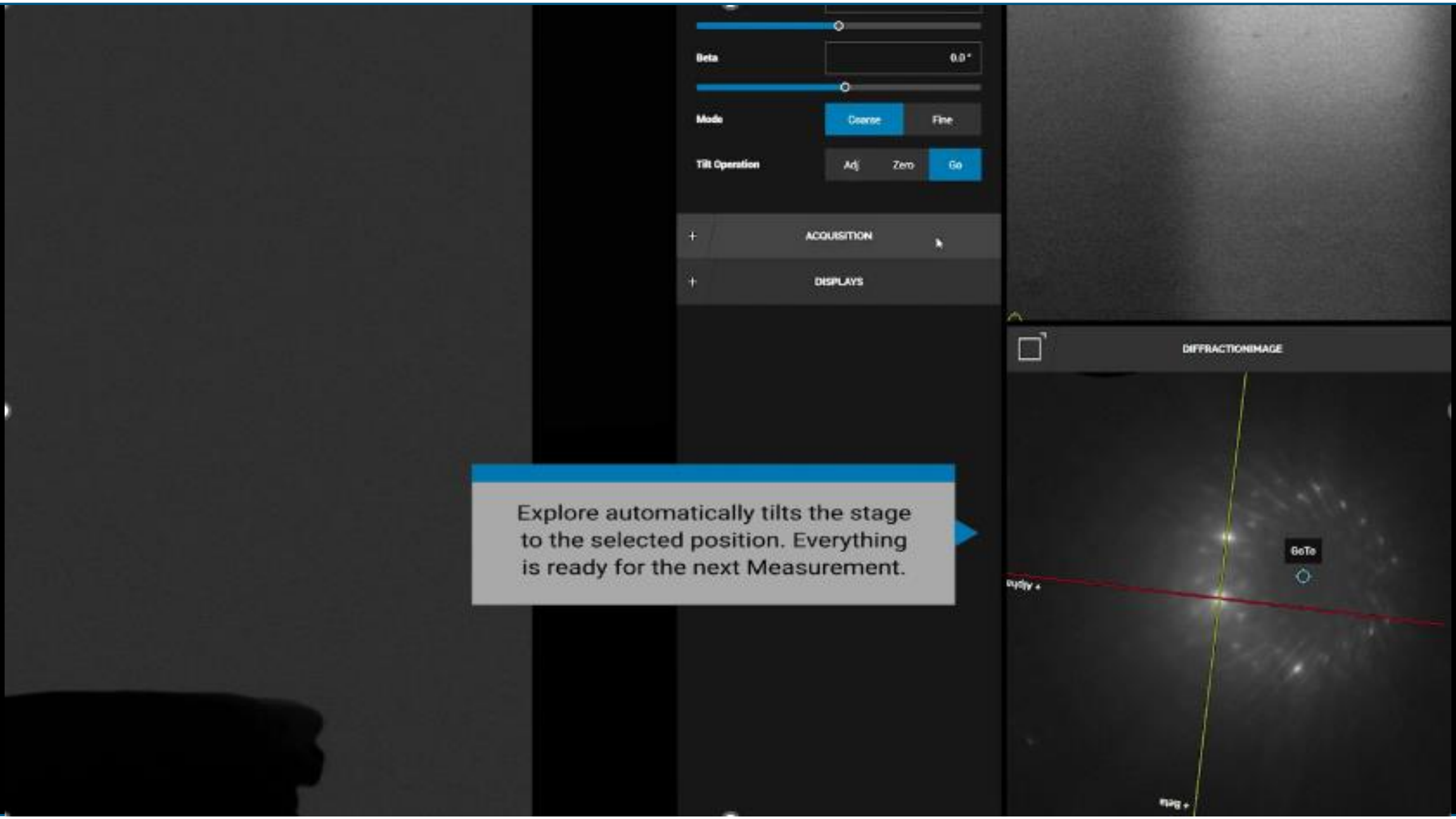
A STEM THAT IS AS EASY TO USE AS A SEM



- Select a Region of Interest (ROI)
- Choose application
- Set acquisition parameters
- Acquire and analyze data

Turning beam precession on and off

A STEM THAT IS AS EASY TO USE AS A SEM



Select a Region of Interest (ROI)

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Aligning the sample to a zone axis

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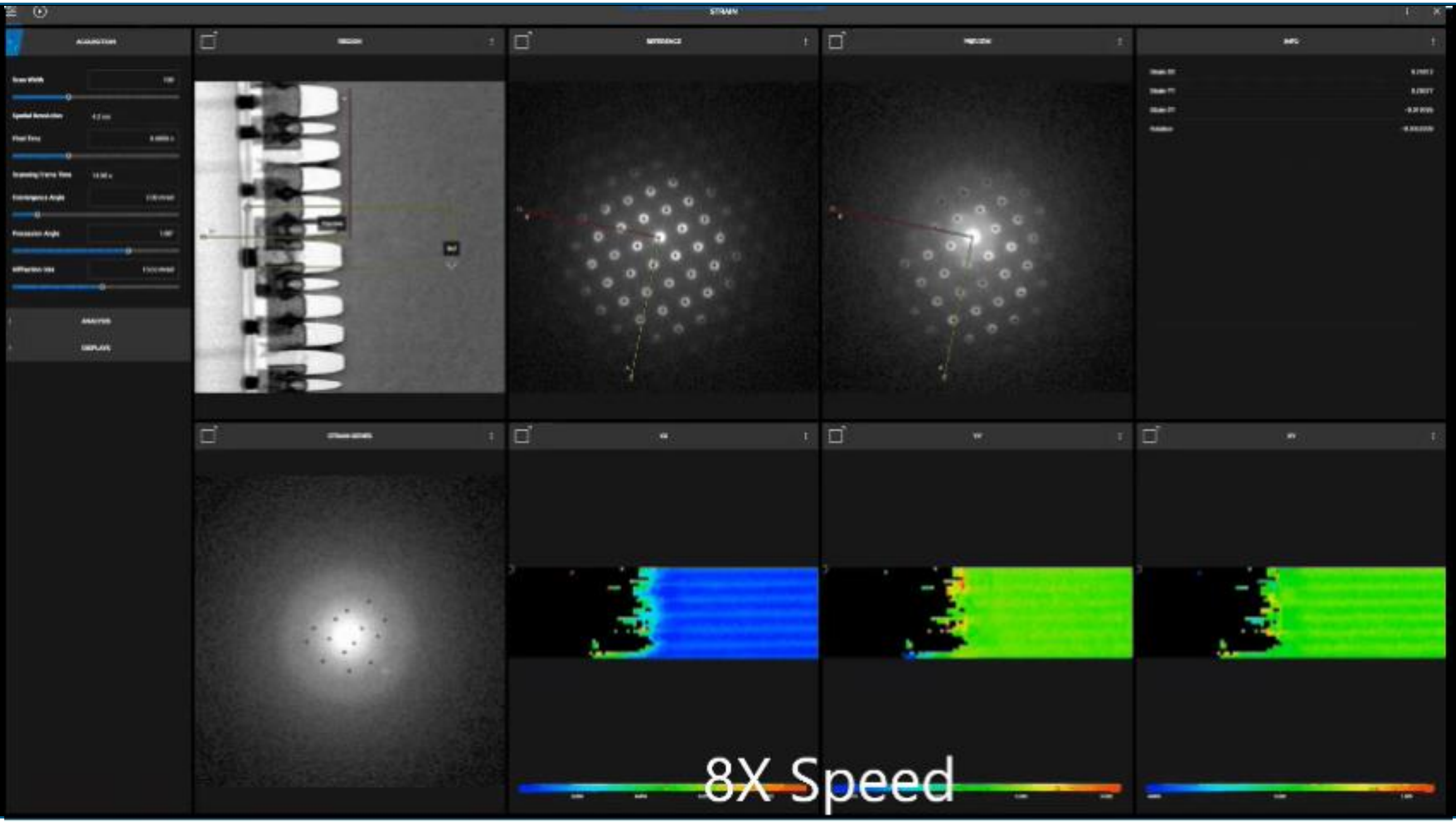

Select a Region of Interest (ROI)

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Acquire and analyze data

Multimodal Imaging and Analytical Techniques

- STEM Imaging (BF, ADF & HAADF)
- EDS Analysis and Elemental Mapping
- 4D-STEM Orientation/Phase Mapping
- 4D-STEM Strain Mapping
- Virtual STEM & Data Export
- STEM Lattice Imaging
- STEM Tomography
- EDS Tomography
- Diffraction Tomography
- API for Custom Experiments

TESCAN TENSOR

TESCAN
PERFORMANCE IN NANOSPACE

THANK YOU!

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