



Reconstruction quantitative 3D de surface à partir d'images BSE multidétecteurs

Jan Neggers

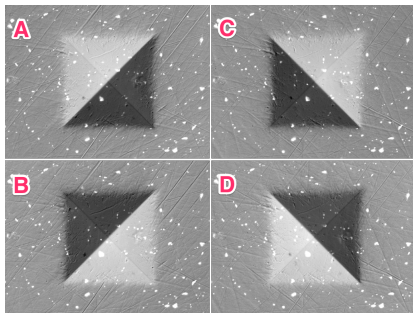
Stéphane Roux, Marc Bonnet, Eva Heripre, Denis Boivin, Alexandre Tanguy, Simon Hallais, Fabrice Gaslain, Elodie Rousne

jan.neggers@ens-paris-saclay.fr

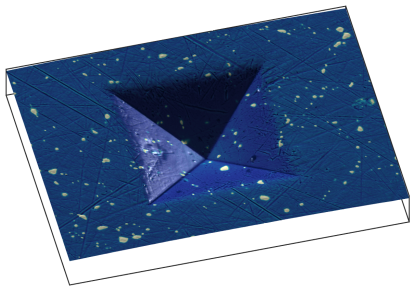
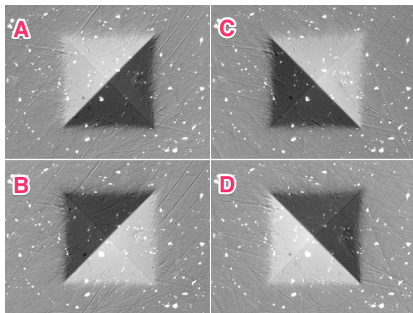
December 7, 2017



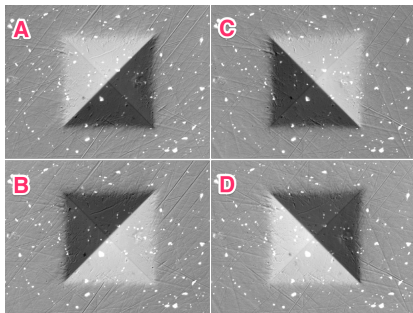
Shape from Shading



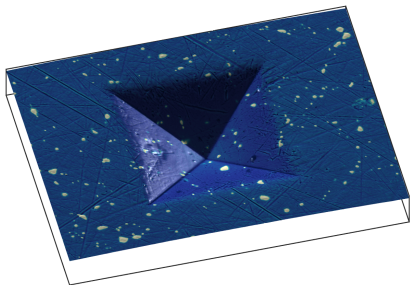
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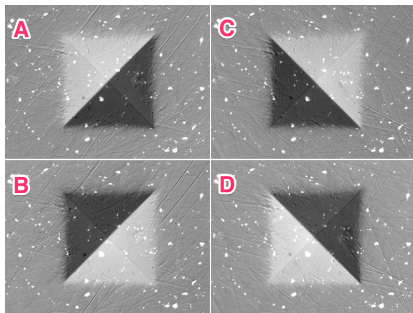
Shape from Shading



4-Quadrant BSE



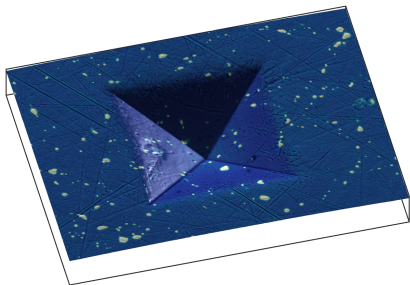
Shape from Shading



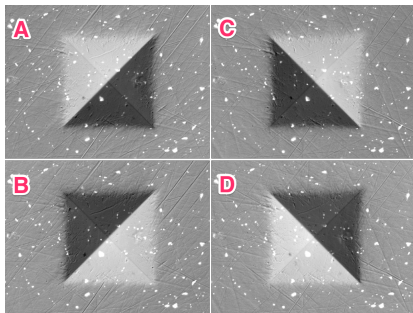
4-Quadrant BSE



Generalize to N-detectors



Shape from Shading



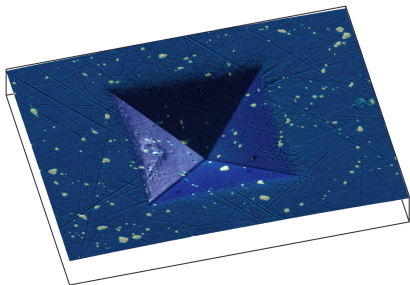
4-Quadrant BSE



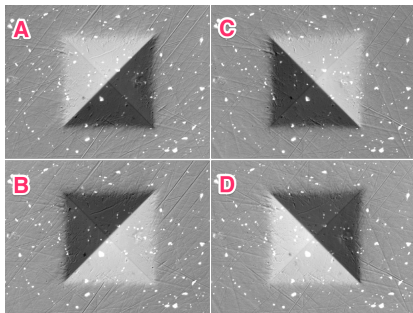
Generalize to N-detectors



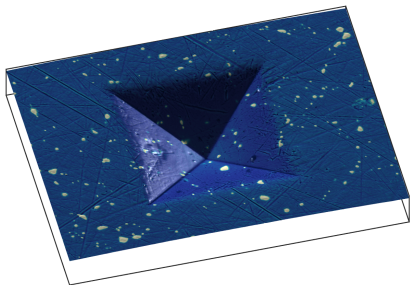
Non-equal detectors



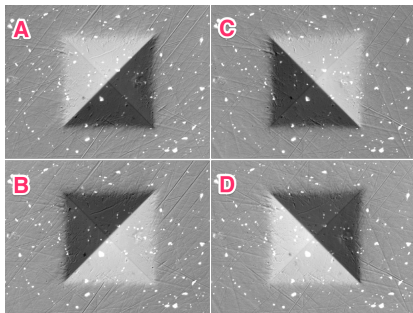
Shape from Shading



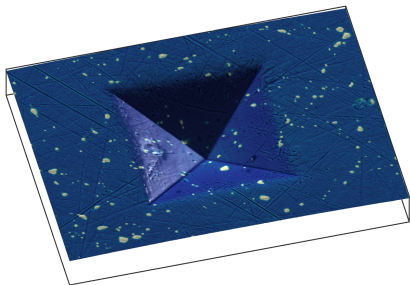
- 4-Quadrant BSE
- Generalize to N-detectors
- Non-equal detectors
- Robust



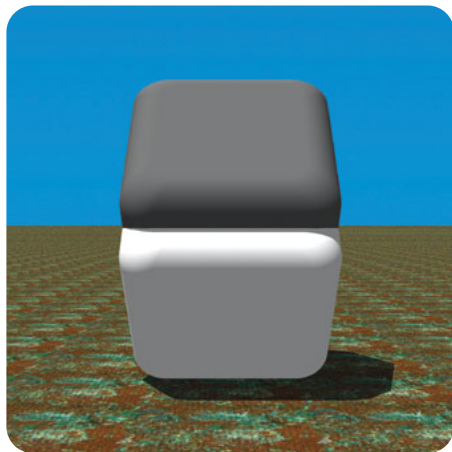
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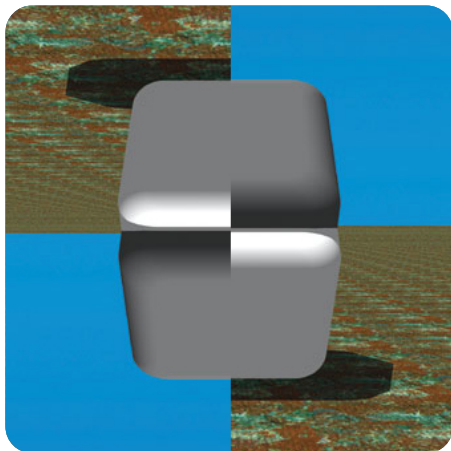
- 4-Quadrant BSE
- Generalize to N-detectors
- Non-equal detectors
- Robust
- Metrology



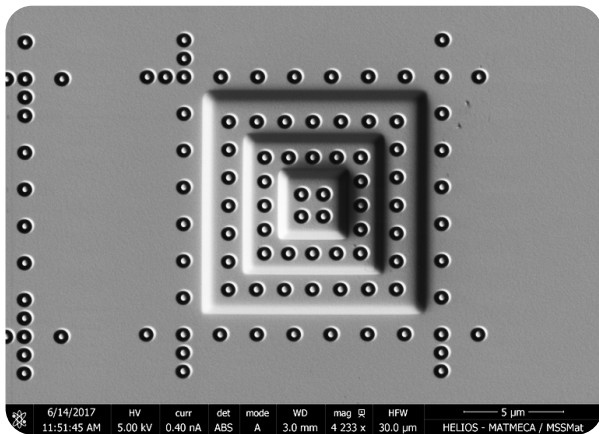
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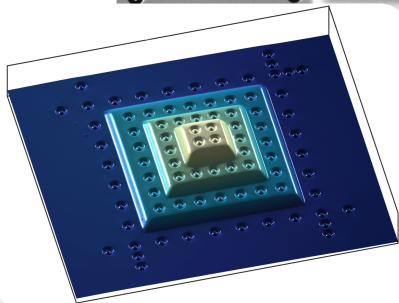
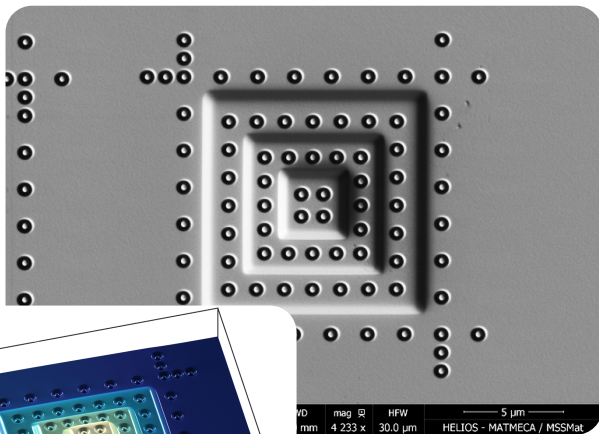
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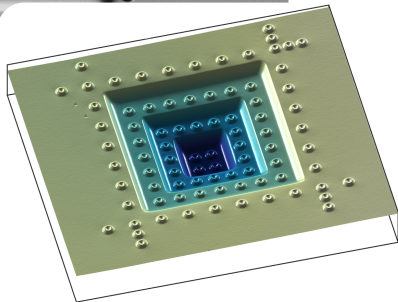
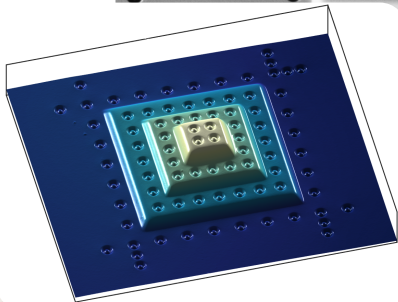
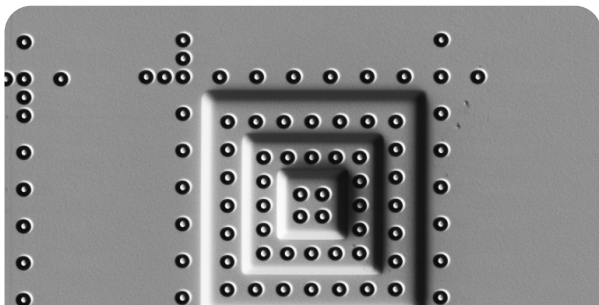
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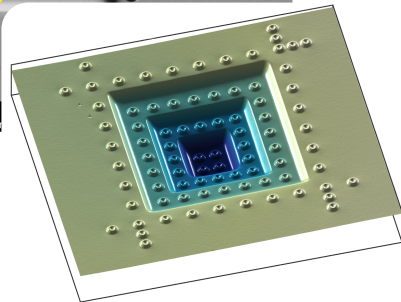
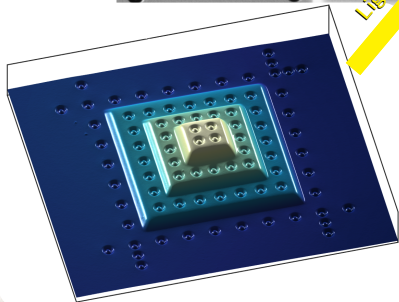
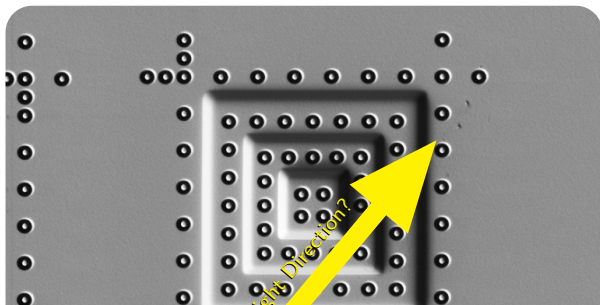
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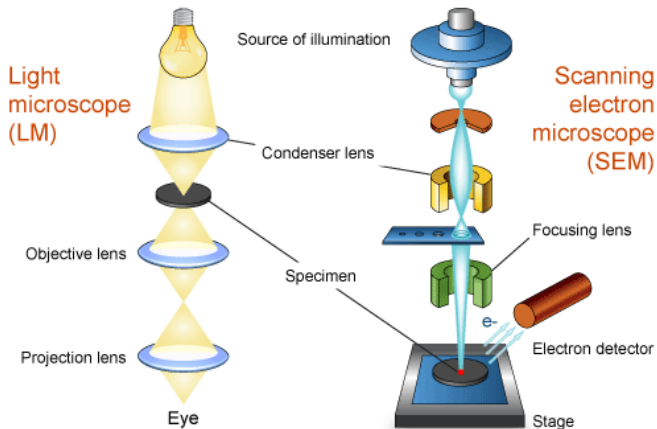
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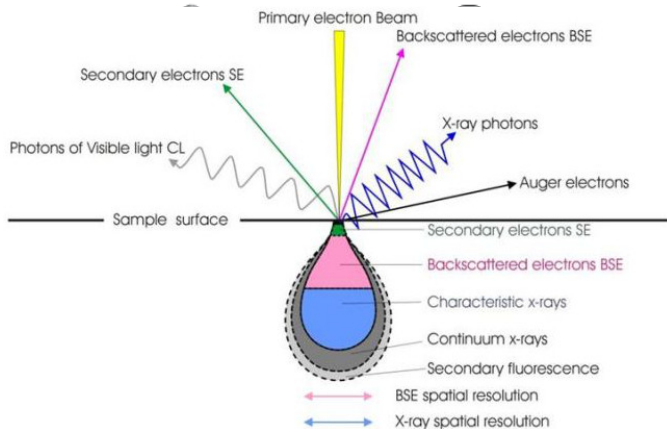
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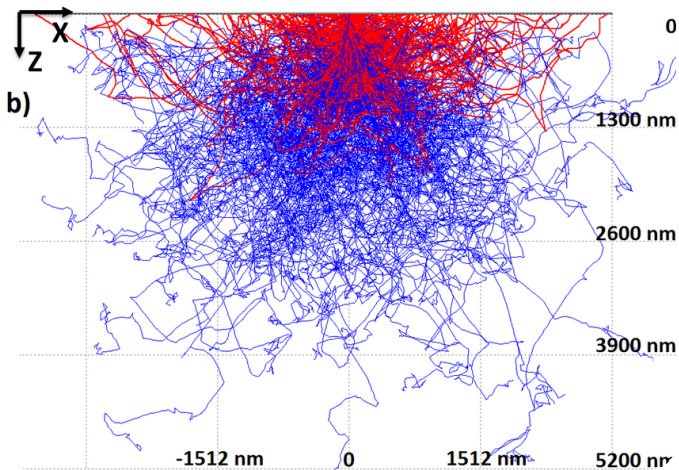
Scanning Electron Microscopy



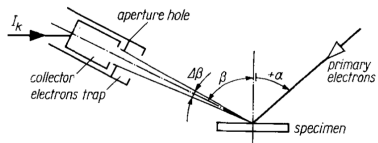
Scanning Electron Microscopy



Scanning Electron Microscopy

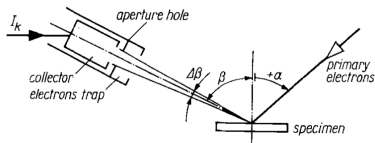


Angular intensity distribution

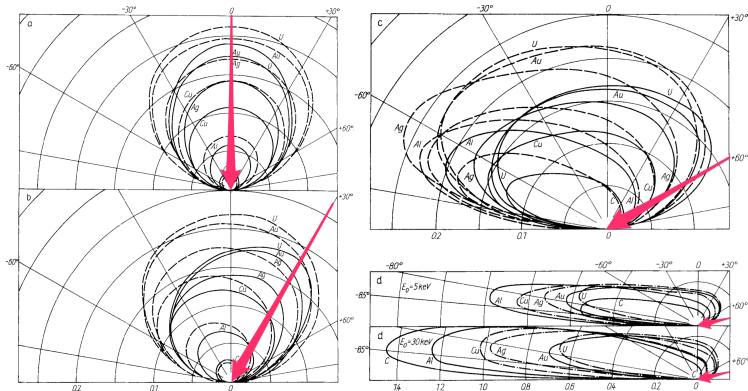


Darliński 1981

Angular intensity distribution

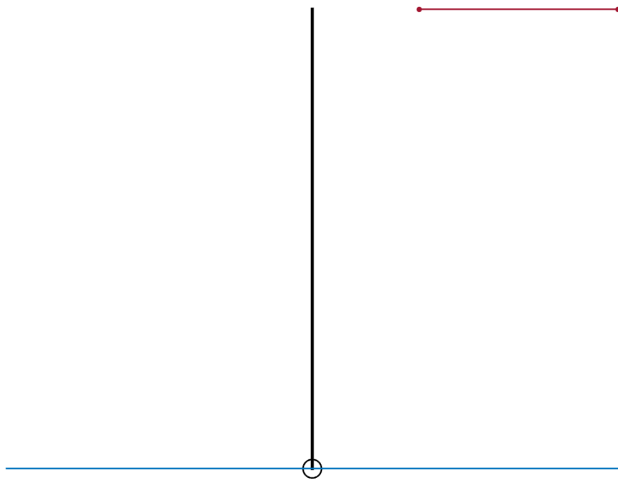


Darliński 1981

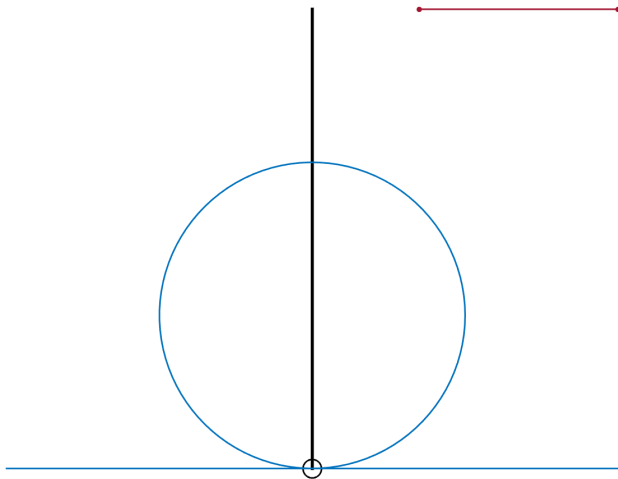


Darliński 1981

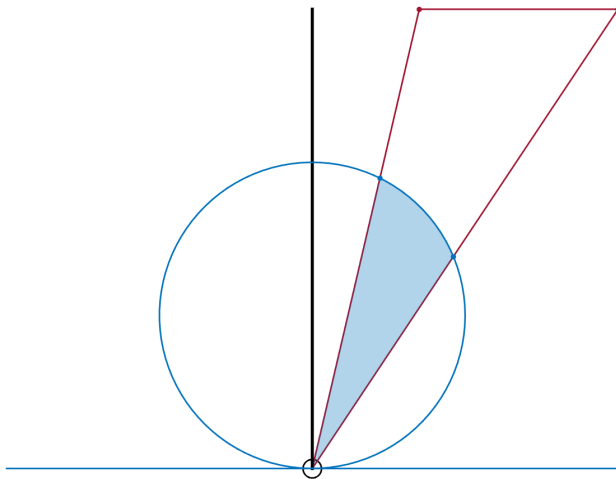
Detector Intensity



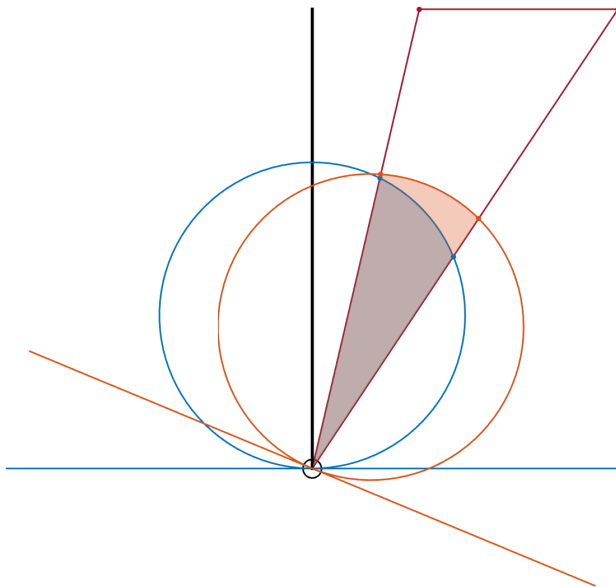
Detector Intensity



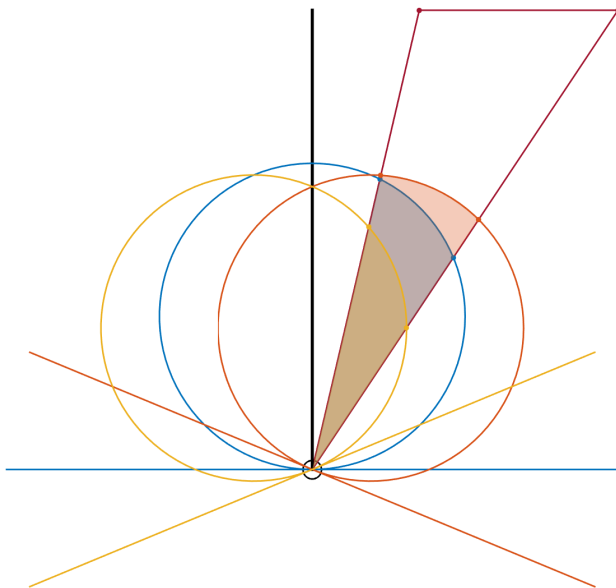
Detector Intensity



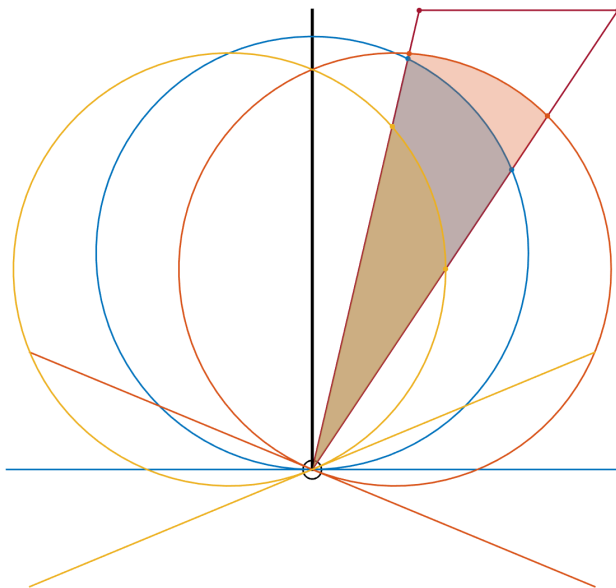
Detector Intensity



Detector Intensity



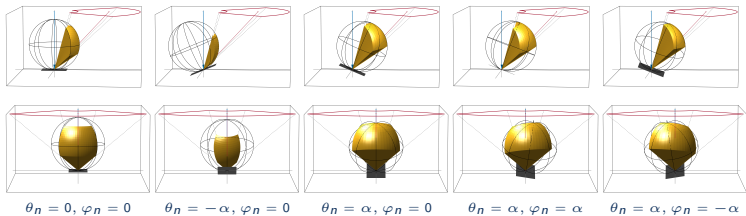
Detector Intensity



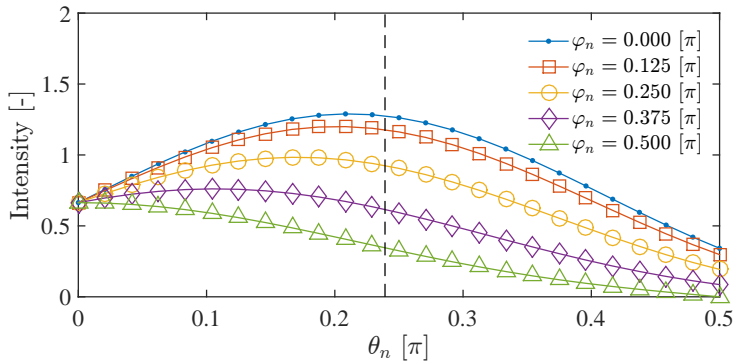
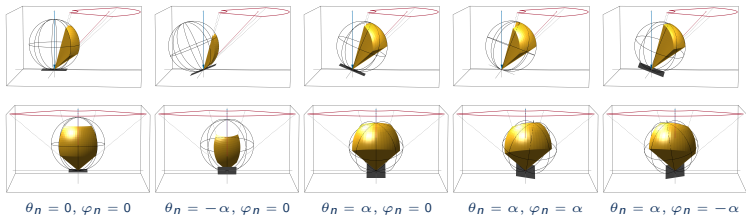
Intensity volume



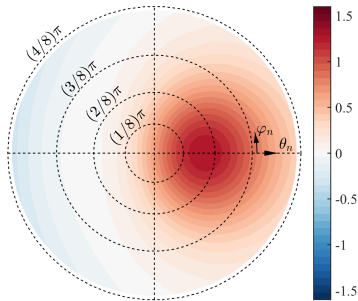
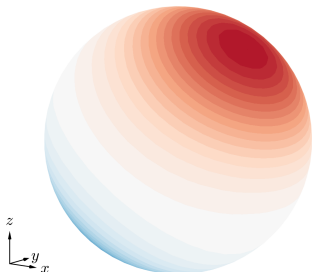
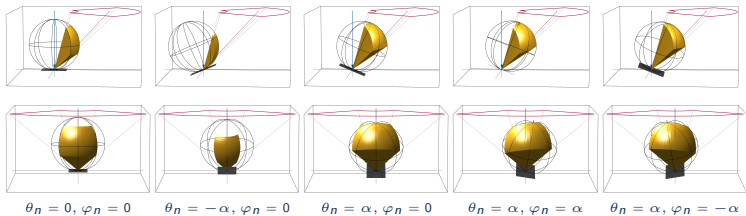
Observed intensity and Surface orientation



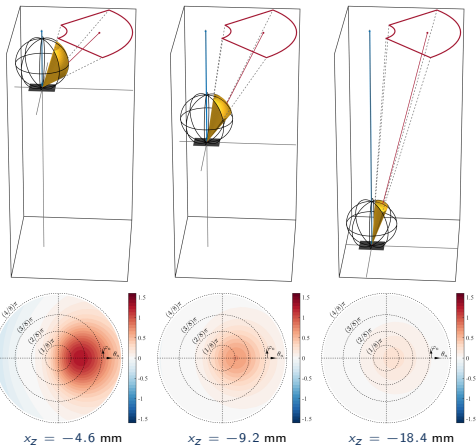
Observed intensity and Surface orientation



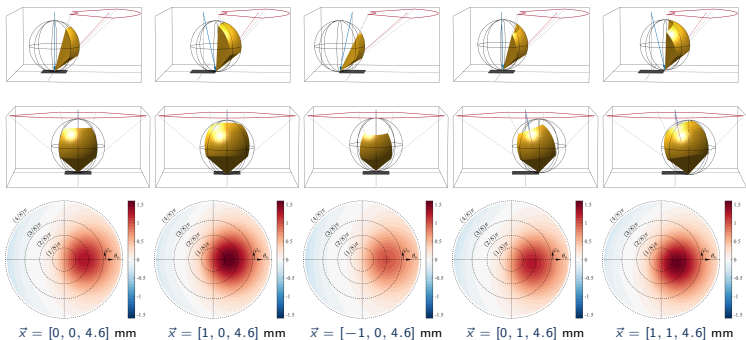
Observed intensity and Surface orientation



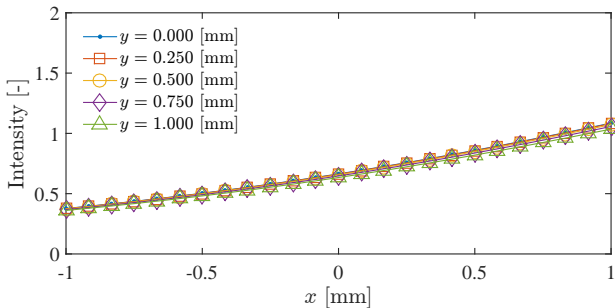
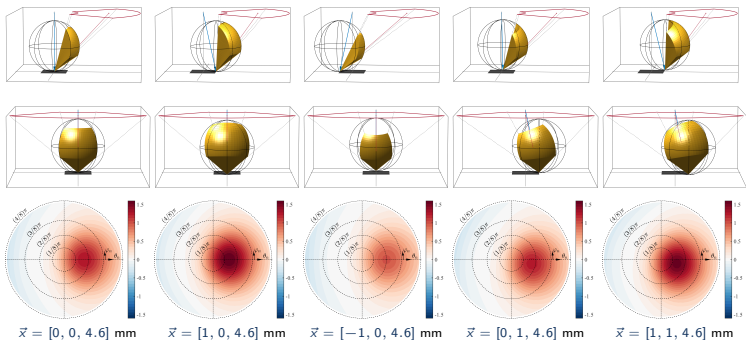
Observed intensity and Working Distance



Observed intensity and Position

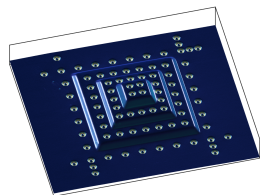


Observed intensity and Position





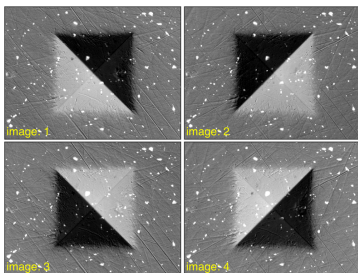
Algorithm 1



Shape from Shading for BSE



BSE Images



4-Quadrant BSE Images

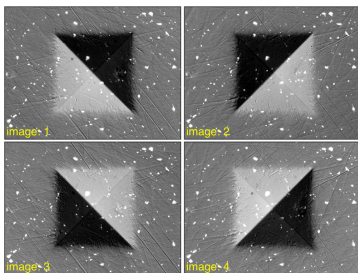
Shape from Shading for BSE



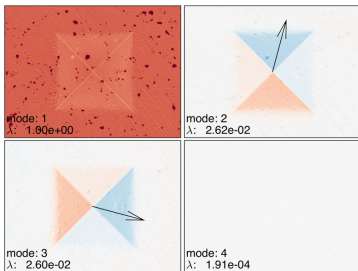
BSE Images



Eigen Images



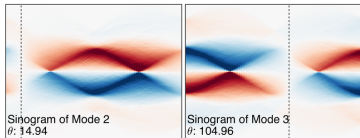
4-Quadrant BSE Images



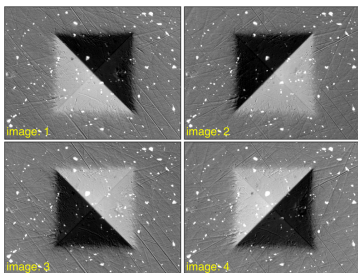
Eigen-Images

Shape from Shading for BSE

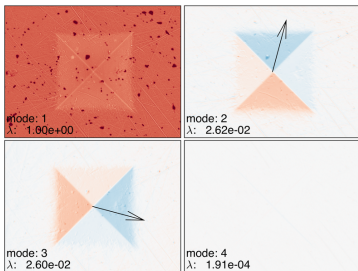
- BSE Images
- Eigen Images
- Sinograms



Sinograms



4-Quadrant BSE Images



Eigen-Images

Shape from Shading for BSE



BSE Images



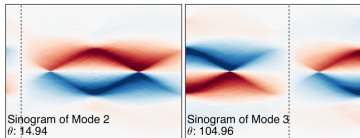
Eigen Images



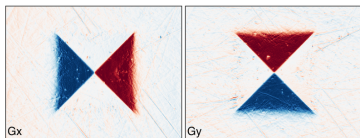
Sinograms



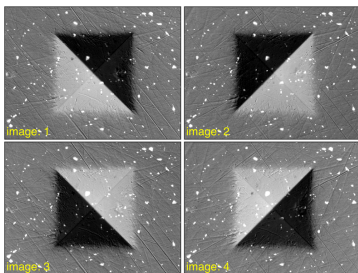
Gradient Images



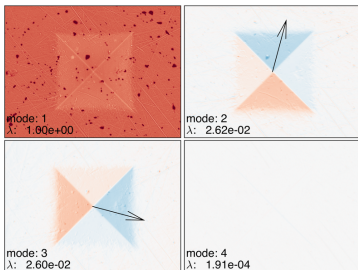
Sinograms



Surface Gradients

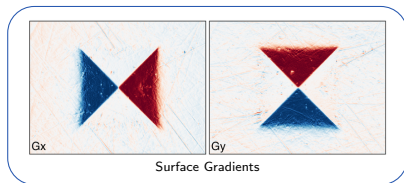


4-Quadrant BSE Images

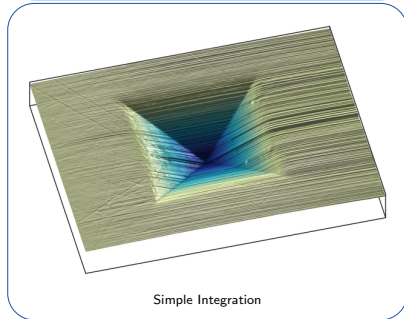
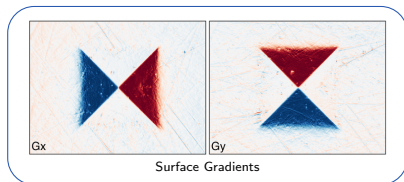


Eigen-Images

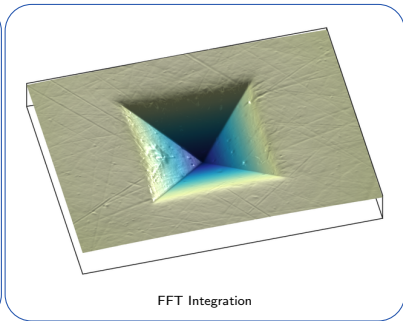
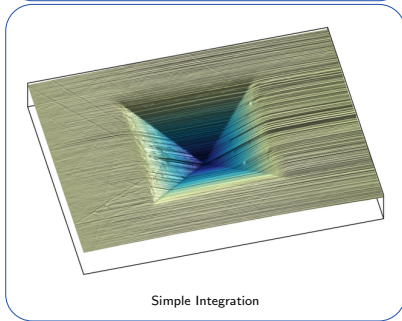
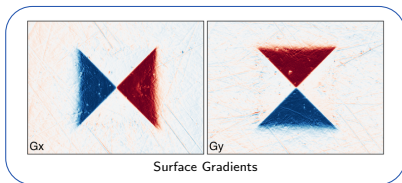
Shape from Shading for BSE - Integration



Shape from Shading for BSE - Integration

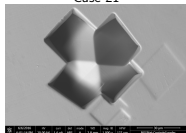


Shape from Shading for BSE - Integration

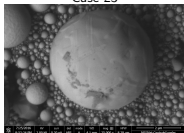


Challenges

Case 21



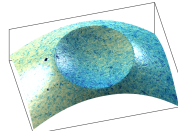
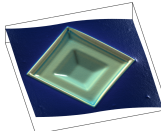
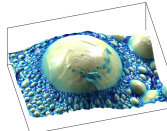
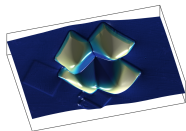
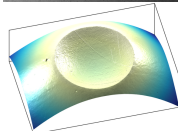
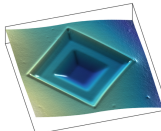
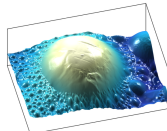
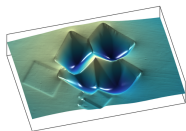
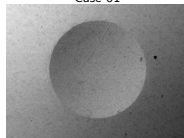
Case 23



Case 43

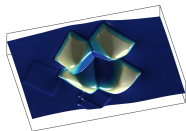
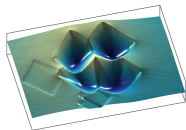
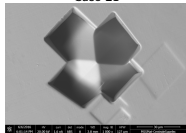


Case 61

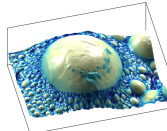
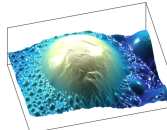
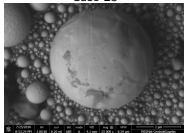


Challenges

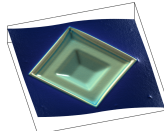
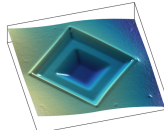
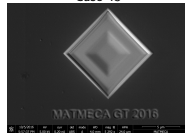
Case 21



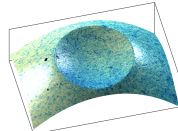
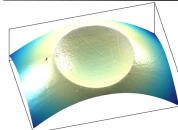
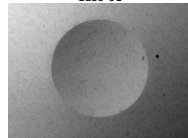
Case 23



Case 43



Case 61



Electron Trapping



Angle Detection



Unknown Z-amplitude



Background Curvature

Building on Algo 1

Image Model

$$A_i(\{p\}, c, z) = p_{1i} + p_{2i}c(\vec{x})(1 + p_{3i}z_x + p_{4i}z_y)$$

Building on Algo 1

Image Model

$$A_i(\{p\}, c, z) = p_{1i} + p_{2i}c(\vec{x})(1 + p_{3i}z_x + p_{4i}z_y)$$

Cost Function

$$\eta = \int (A_i^{\text{meas.}} - A_i(\{p\}, c, z))^2$$



Start with Algo 1

Building on Algo 1

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Start with Algo 1



Solve for $\{p\}$

4 unknowns per detector

Building on Algo 1

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Start with Algo 1



Solve for $\{p\}$

4 unknowns per detector



Solve for c and z

2 unknowns per pixel

Building on Algo 1

Image Model

$$A_i(\{p\}, c, z) = p_{1i} + p_{2i}c(\vec{x})(1 + p_{3i}z_x + p_{4i}z_y)$$

Cost Function

$$\eta = \int (A_i^{\text{meas.}} - A_i(\{p\}, c, z))^2$$



Start with Algo 1



Solve for $\{p\}$

4 unknowns per detector



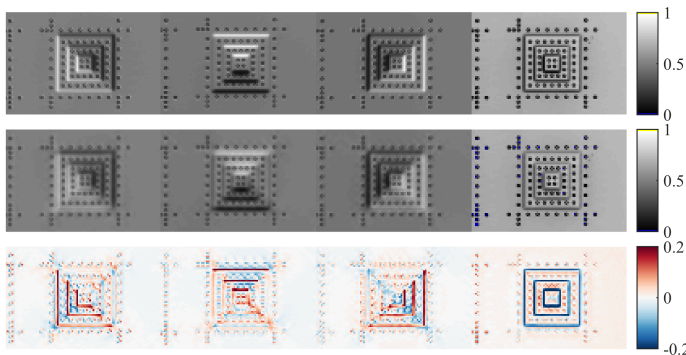
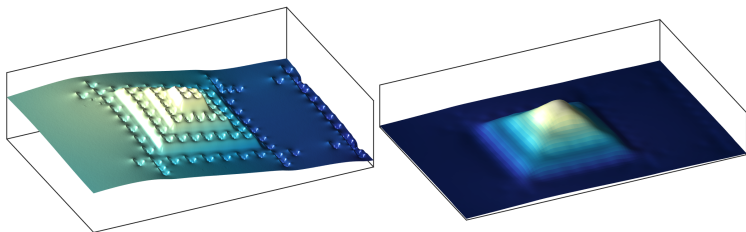
Solve for c and z

2 unknowns per pixel

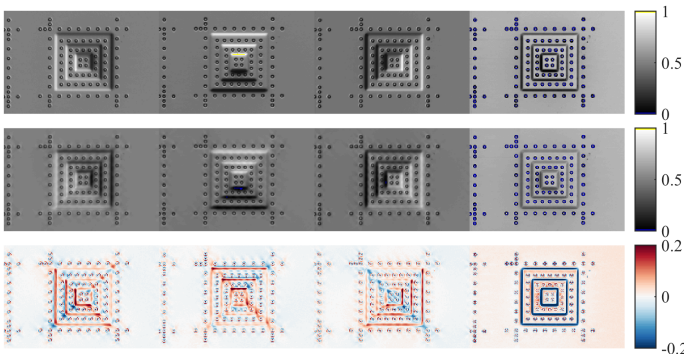
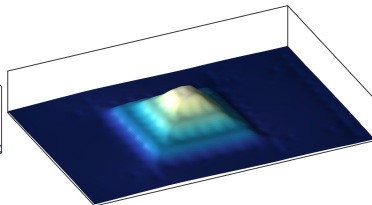
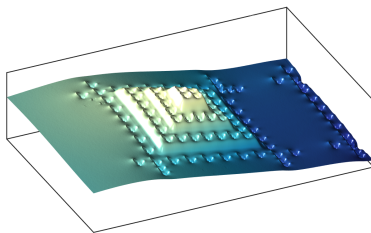


FFT Integration method

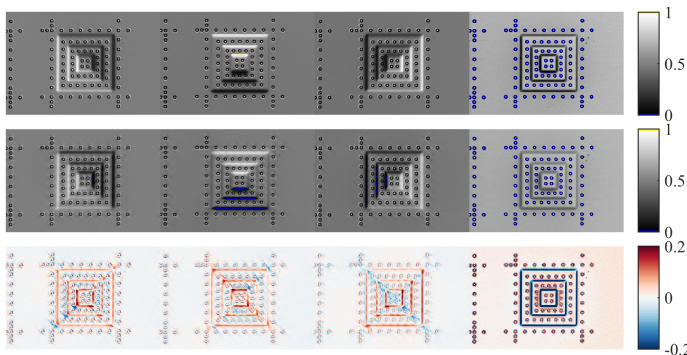
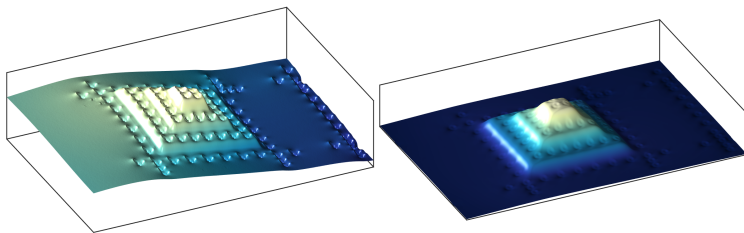
Working Distance 3 mm



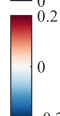
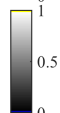
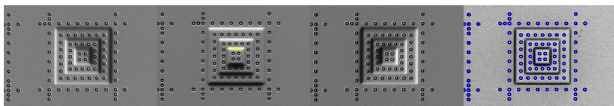
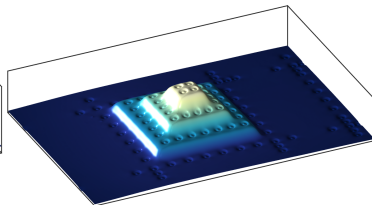
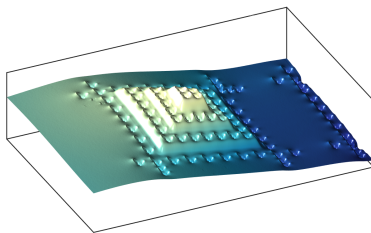
Working Distance 3 mm



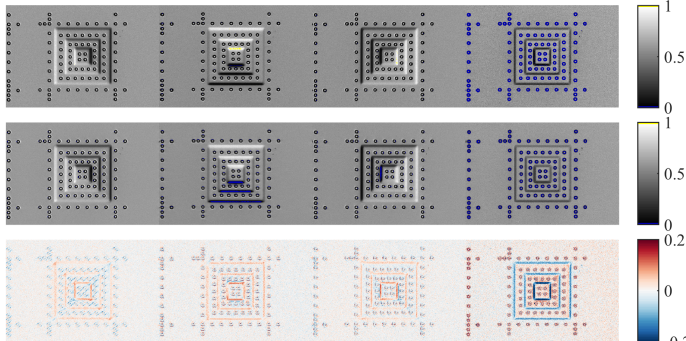
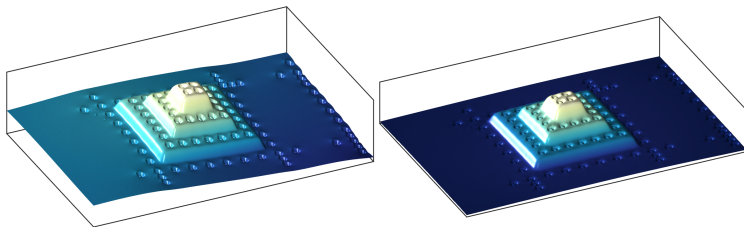
Working Distance 3 mm



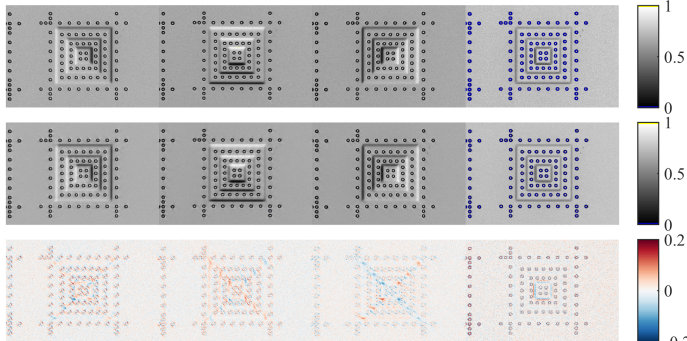
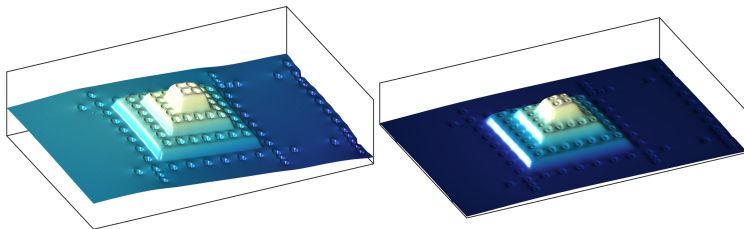
Working Distance 3 mm



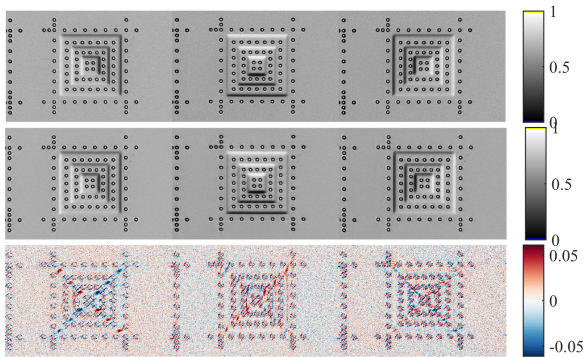
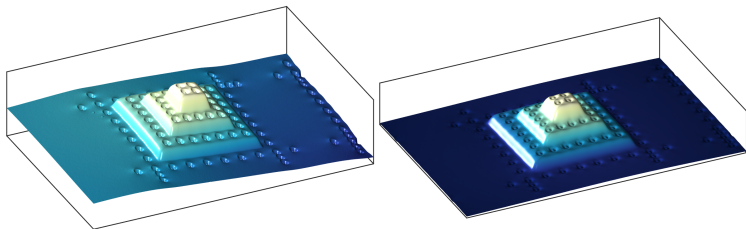
Working Distance 4 mm



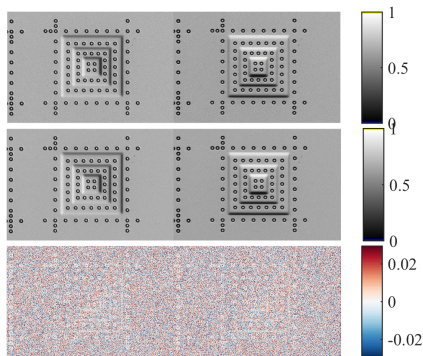
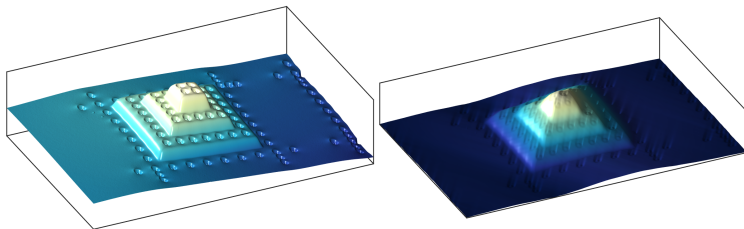
Working Distance 5 mm



Working Distance 5 mm - 3 Detectors



Working Distance 5 mm - 2 Detectors



Shape from Shading for BSE



Algorithm 1

- Eigen Images
- 3 Detectors
- Smart Integration
- Fast
- Simple Cases

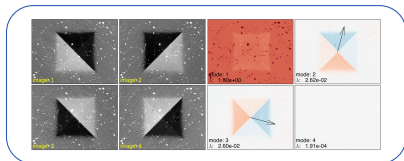
Shape from Shading for BSE

Algorithm 1

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Improved Algorithm

- Initialization
- Brightness/Contrast
- Robust
- Zero Calibration



Shape from Shading for BSE

Algorithm 1

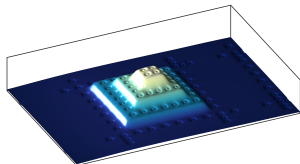
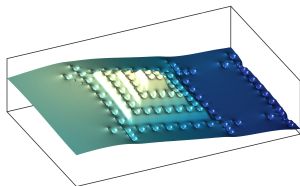
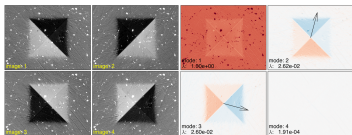
- Eigen Images
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- Simple Cases

Improved Algorithm

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Issues

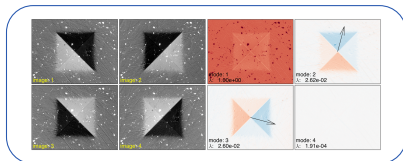
- Z amplitude
- Altitude jumps
- Electron blocking



Shape from Shading for BSE

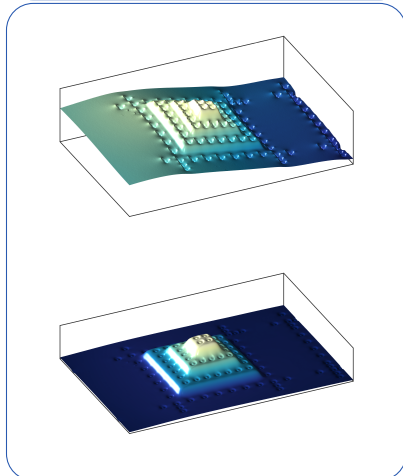
Algorithm 1

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Improved Algorithm

- Initialization
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Issues

- Z amplitude
- Altitude jumps
- Electron blocking

Prospects

- Include DIC
- User Interface

