Imaging Strain in Semiconductor Nanowires by Means of Coherent X-Ray Diffraction Imaging

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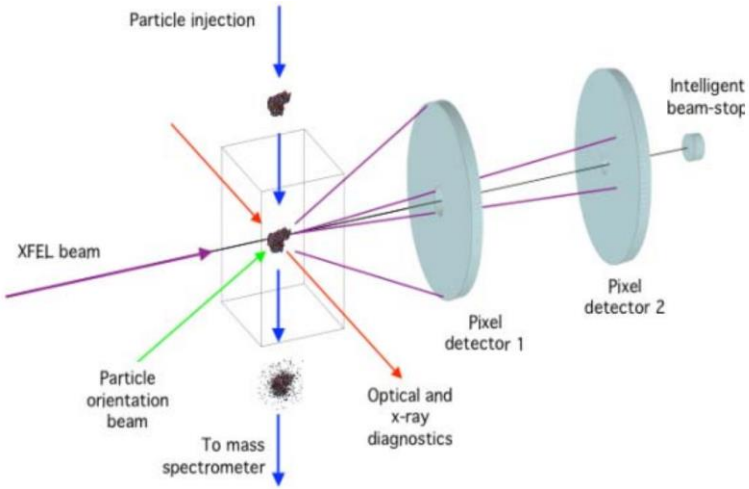
Ultrafast Beams and Applications
02-05 July 2019, CANDLE, Armenia

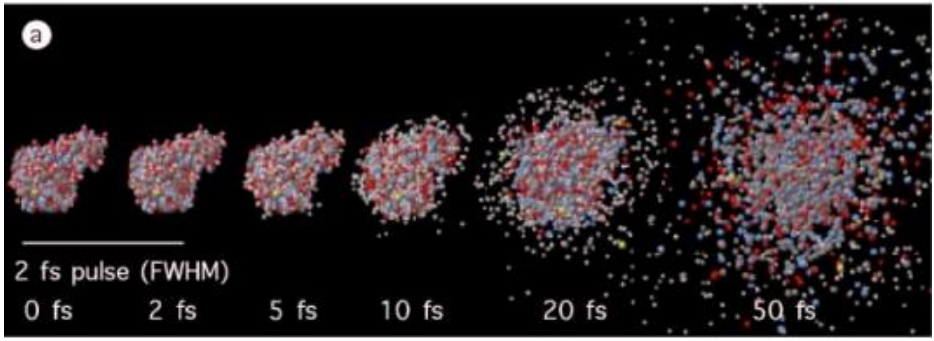
Single particle imaging

ULTRAFAST COHERENT DIFFRACTION IMAGING WITH X-RAY FREE-ELECTRON LASERS

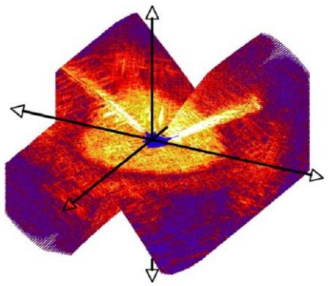


Schematic diagram :
single-particle diffraction imaging experiment at an XFEL

Simulation of radiation-induced Coulomb explosion of a small protein (lysozyme)

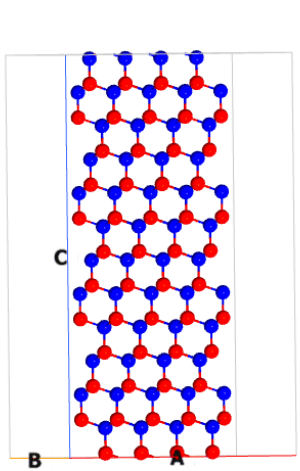


Three-dimensional diffraction data



H. N. Chapman et al. Proceedings of FEL 2006, BESSY, Berlin, Germany

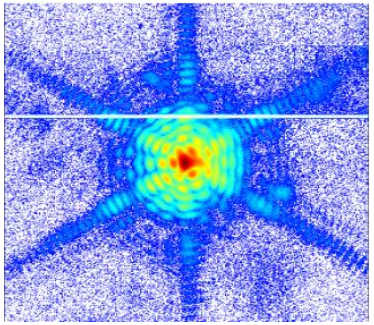
Outline



Ga
As

- Motivation
- III-V Semiconductor nanowires
- Core-shell-shell nanowires

- Coherent X-Ray Diffraction Imaging
- Solving the CXDI for single wire
- Ptychography



- Discussion

CXDI=Bragg Coherent X-Ray Diffraction Imaging

Introduction to GaAs NW

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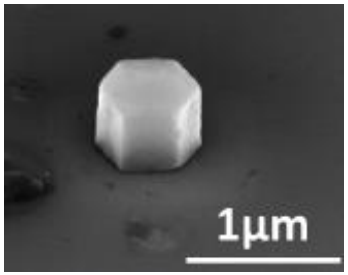
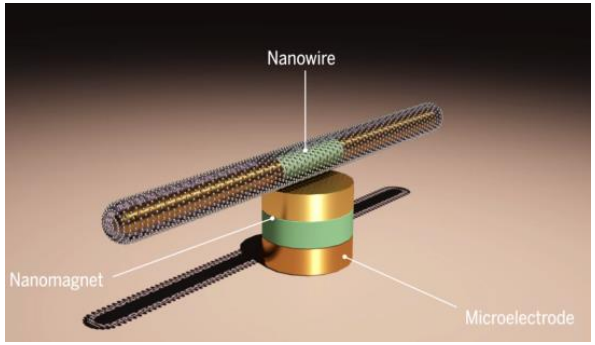
Nanowires: Novel Material → ***Novel devices***

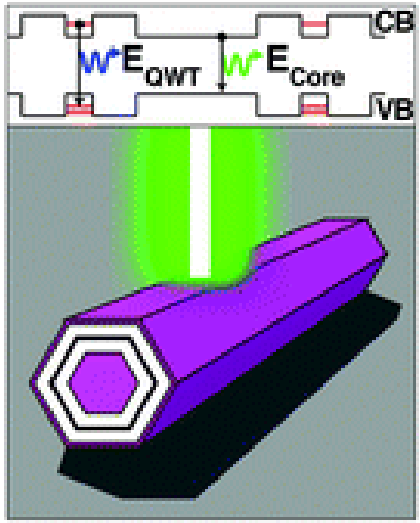


Scanning Electron Microscopy image of a single nanowire

1nm = 0.0000001 cm



Nature communications, 2014, 7, 3632



Nanoscale, 2015, 7, 20531

GaAs Nanowire Applications

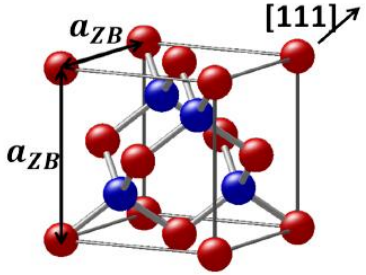
Terahertz detectors
Transistors
Nanolasers
Photovoltaics
Photodetectors and sensors
Light emitting diodes

Motivation

GaAs crystallizes in ZB and WZ phases

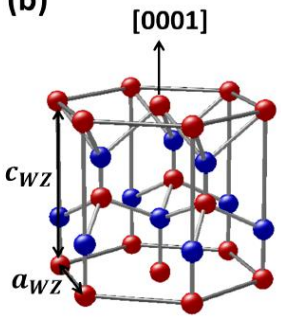
Ga As

(a)



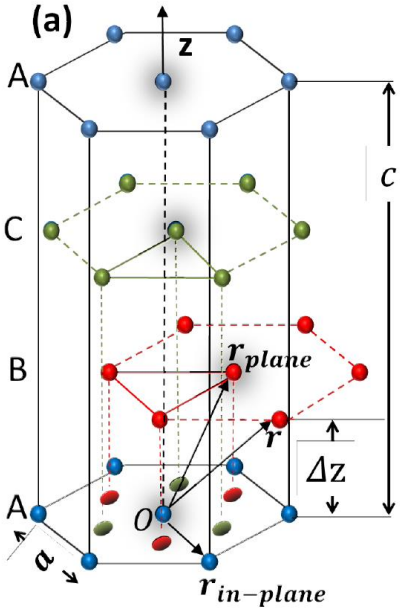
Zincblende (ZB) unit cell

(b)

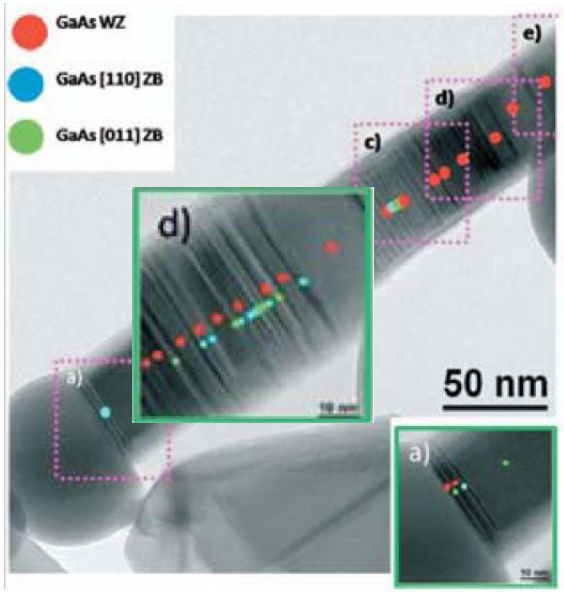


Wurtzite (WZ) unit cell

Structural defects:
Polytypism
Strain
Compositional inhomogeneity
Growth defects

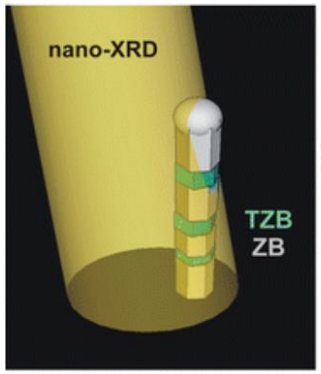


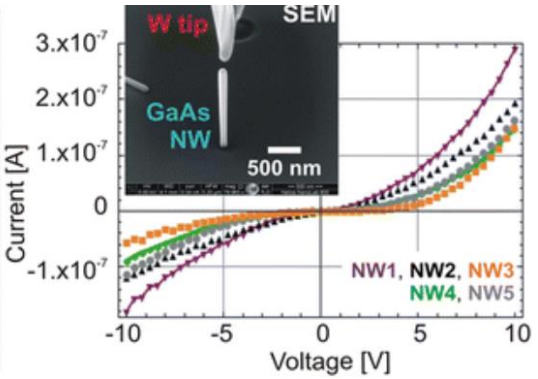
Phys. Rev. B 80 (2009), Nr. 24, S. 245325



Electrical and structural properties are correlated

Nano Lett., 2015, 15 (2), pp 981–989





Core-multi shell NW

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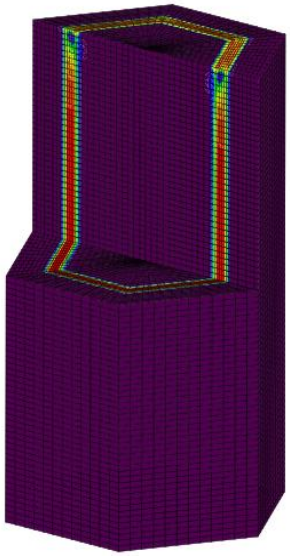
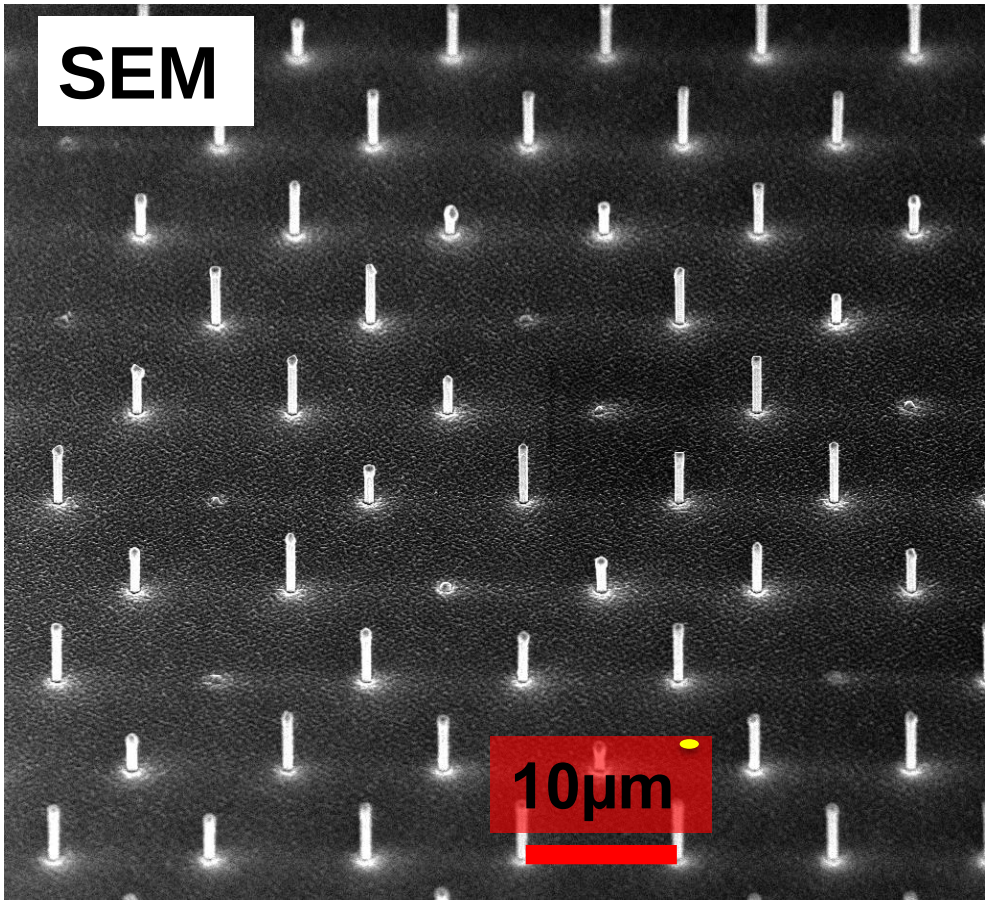
$GaAs/In_{0.1}Ga_{0.9}As/GaAs$

130/10(10%)/30nm



Misfit strain for 15% In

$$\epsilon_{\perp} = \frac{a_{InGaAs} - a_{GaAs}}{a_{GaAs}} \approx 0.7\%$$



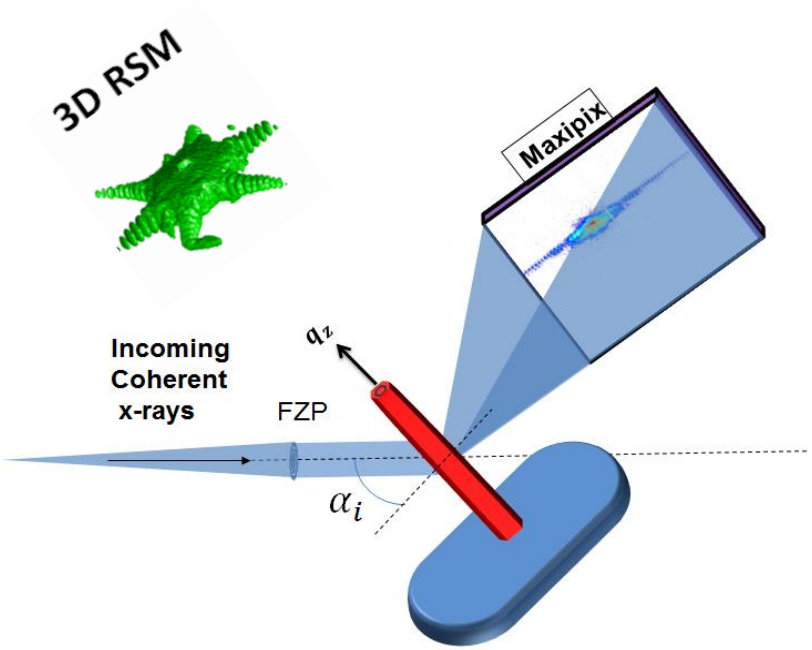
Investigate the same NW via coherent x-ray diffraction imaging and ptychography

Characterizing single NW

ESRF, ID01 microfocusing beamline Beam energy 8keV Beam size ≈150x200nm

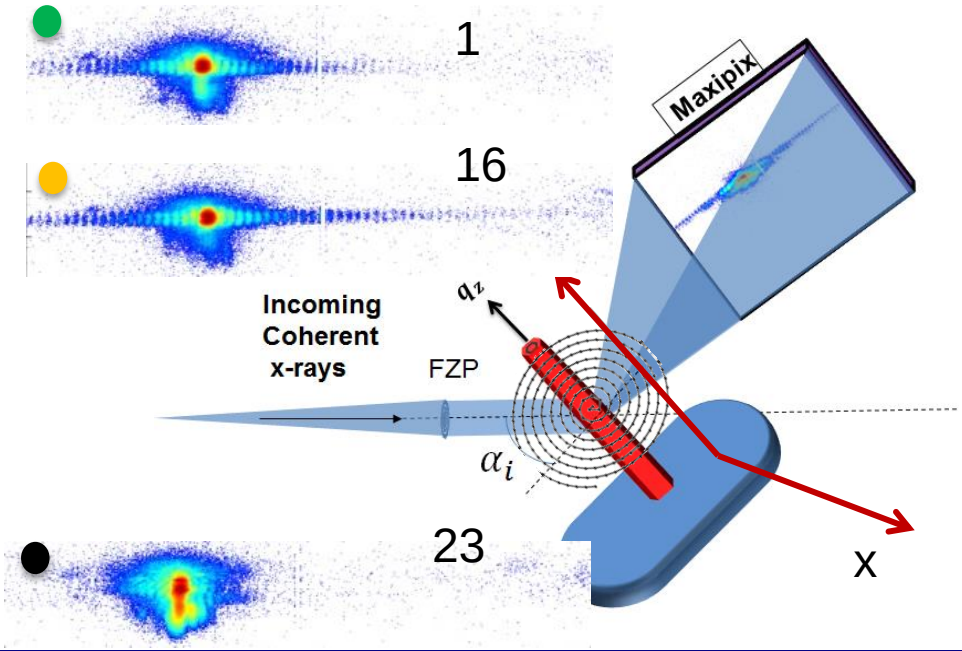
CXDI

Angular scan at certain hight along the NW growth axis



PTYCHOGRAPHY

Translate the NW via piezo motors along and perpendicular to growth direction

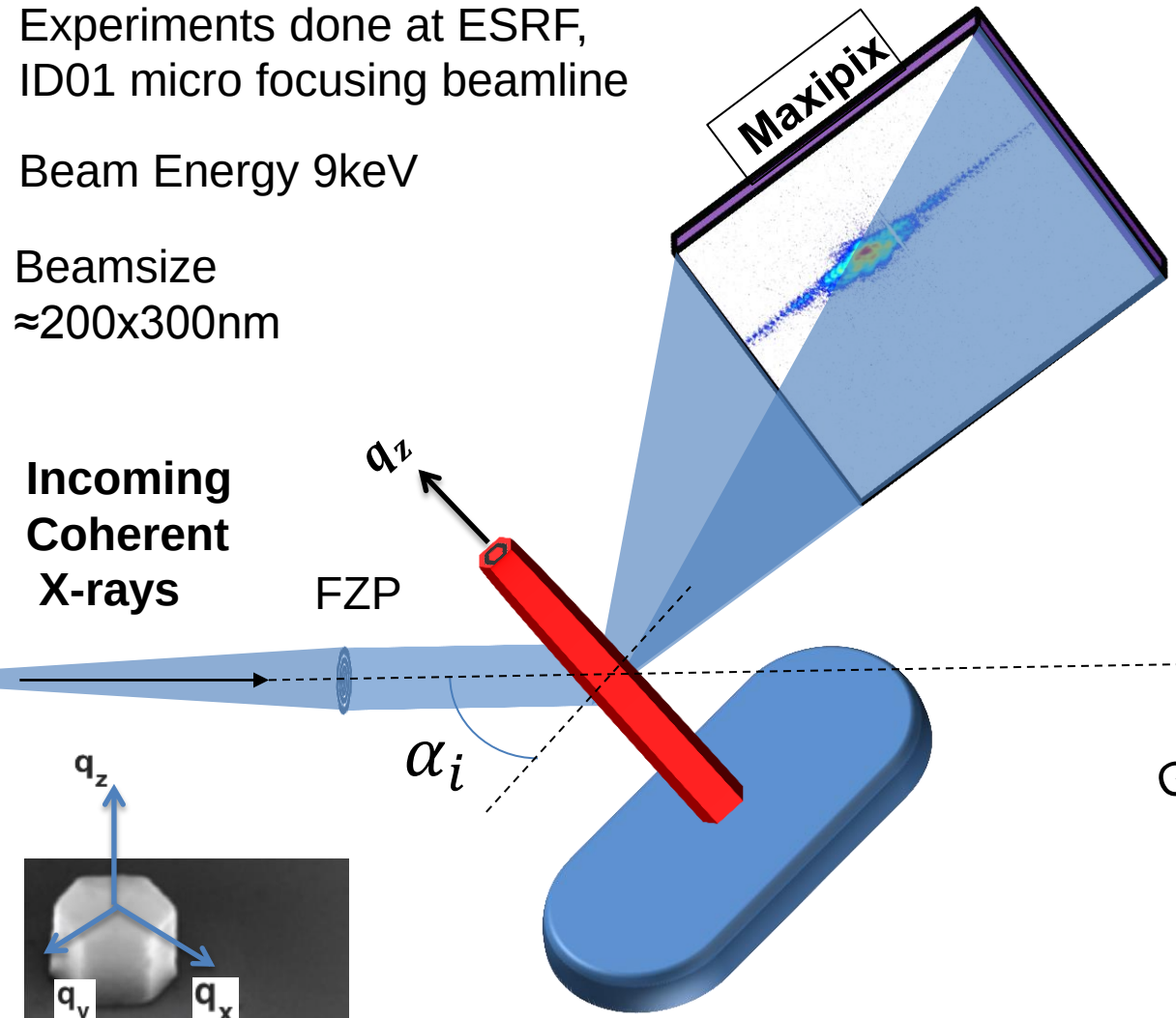


Single NW GaAs 333 reflection

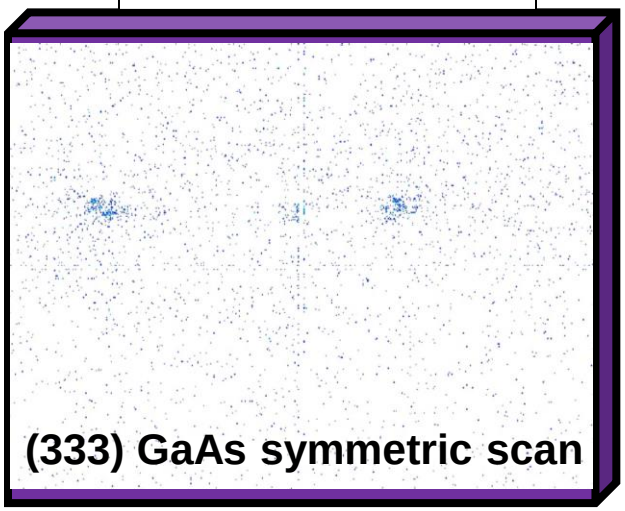
Experiments done at ESRF,
ID01 micro focusing beamline

Beam Energy 9keV

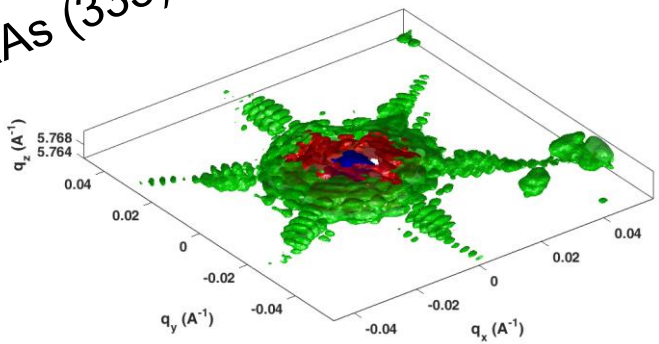
Beamsize
≈200x300nm



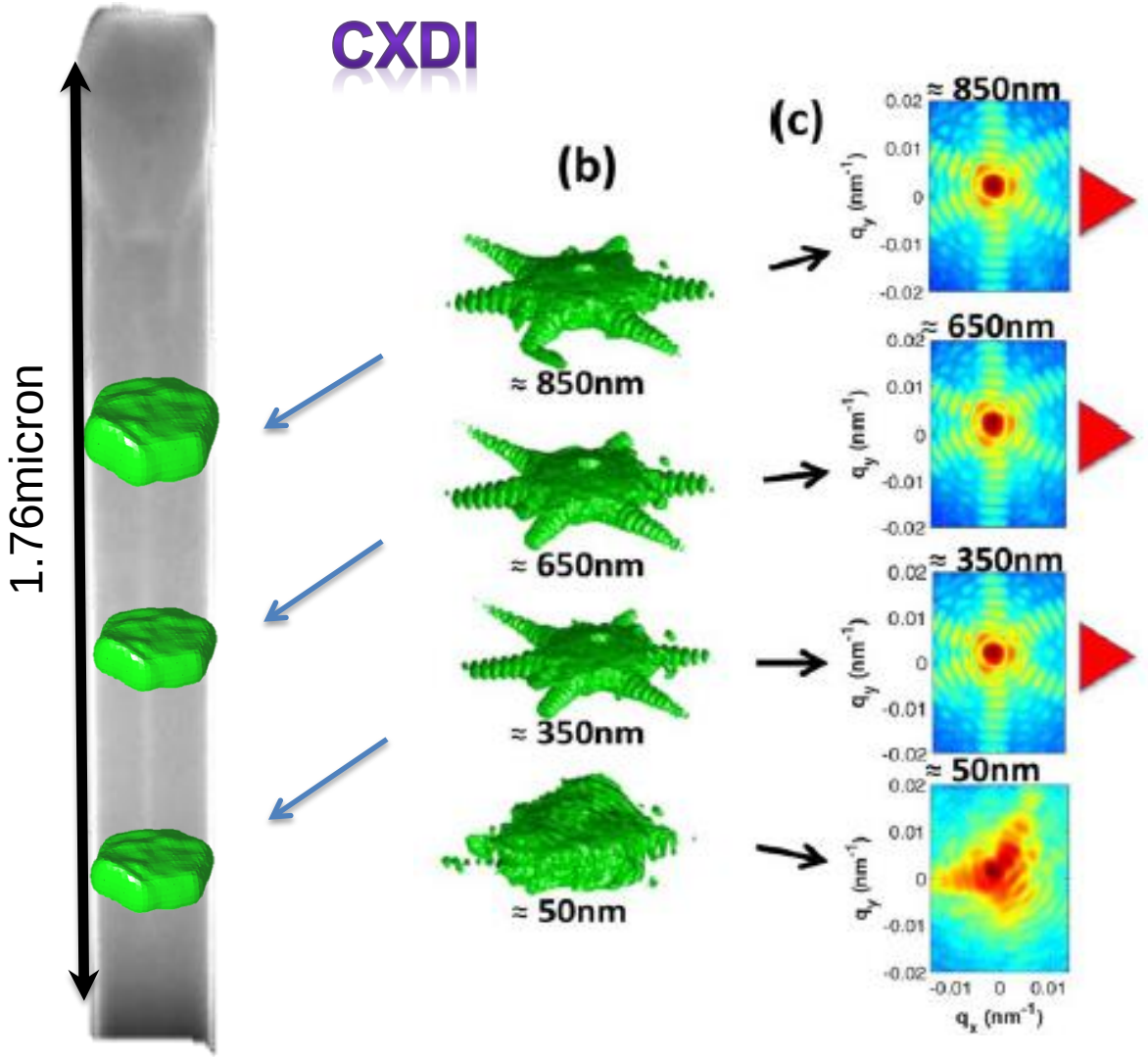
Detector images

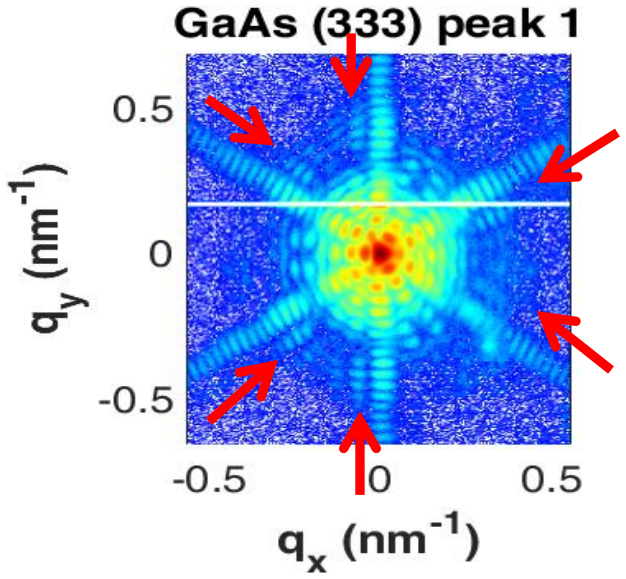


GaAs (333)



Coherent X-ray diffraction: GaAs (111)

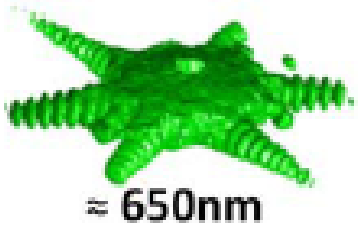




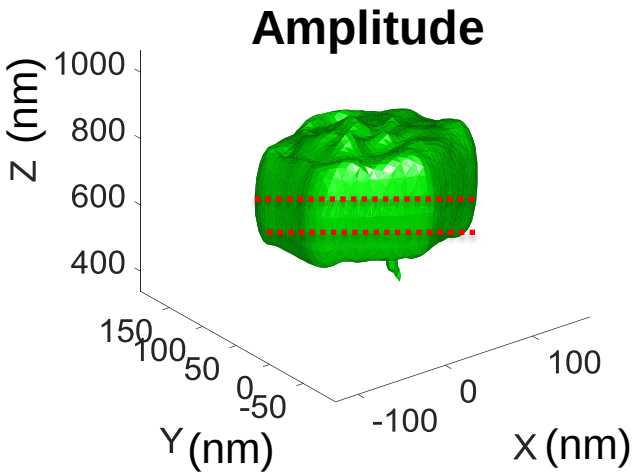
Davtyan et.al. J. Appl. Cryst. (2017). 50, 673-680

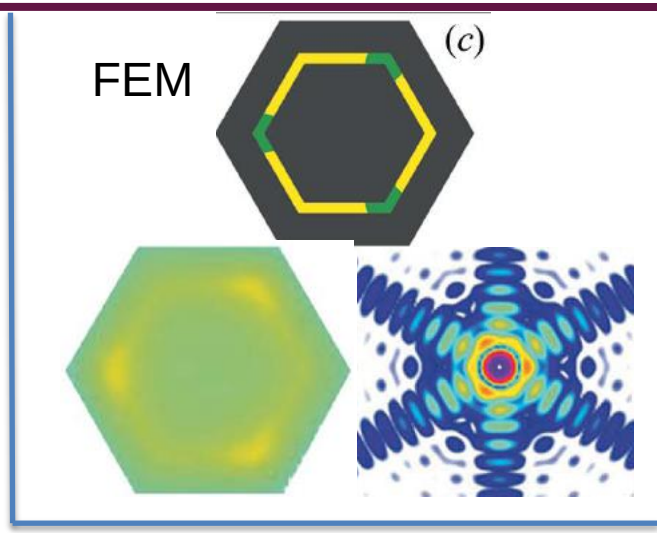
CXDI at symmetric GaAs 111 Bragg reflection confirms the homogeneity of the cross section of the NW at different positions along the growth axis.

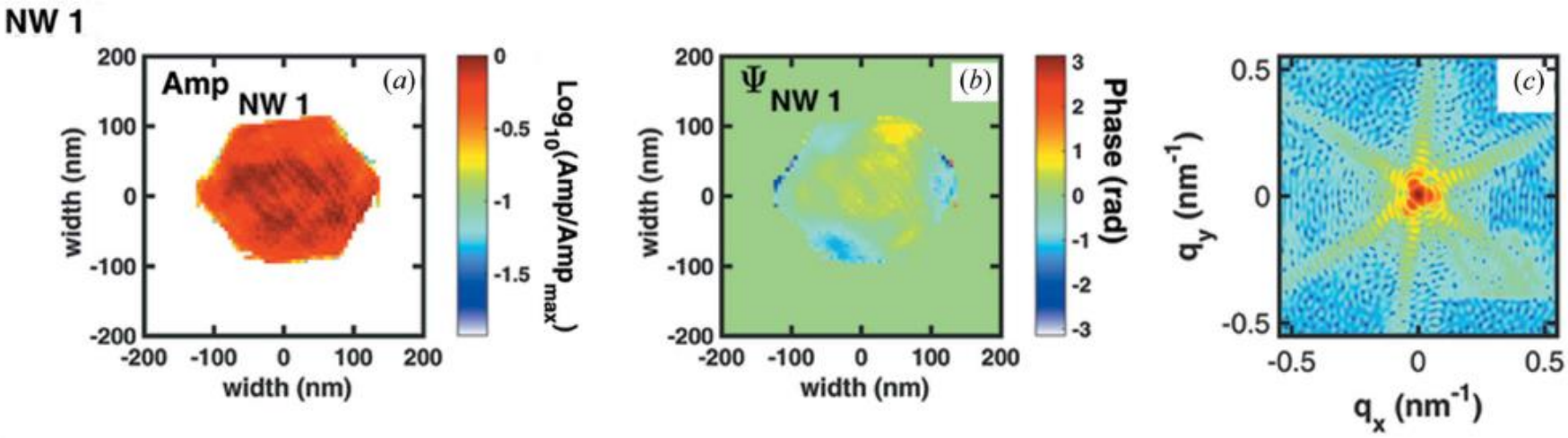
3D phase retrieval: GaAs 111



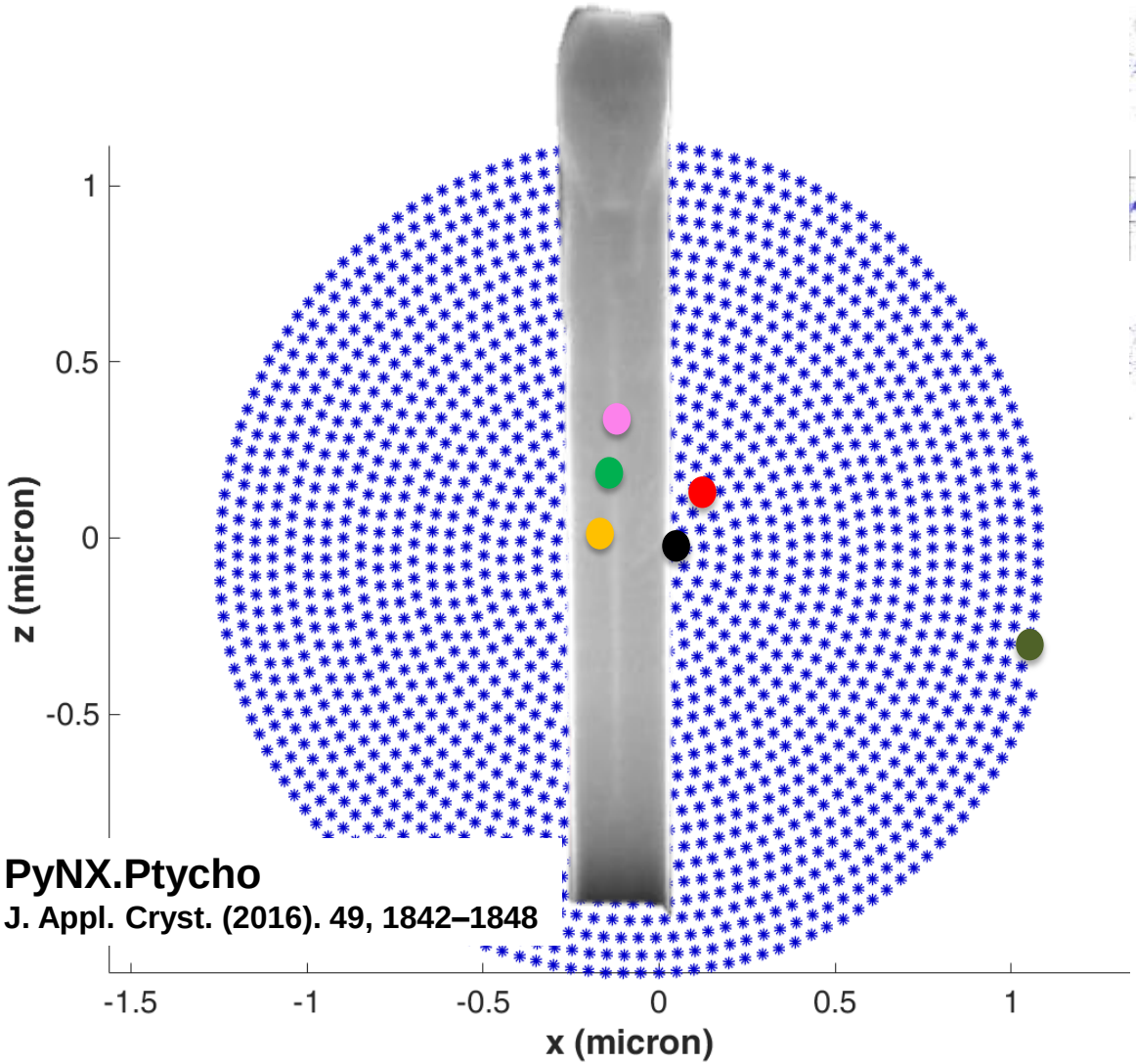
3D PR



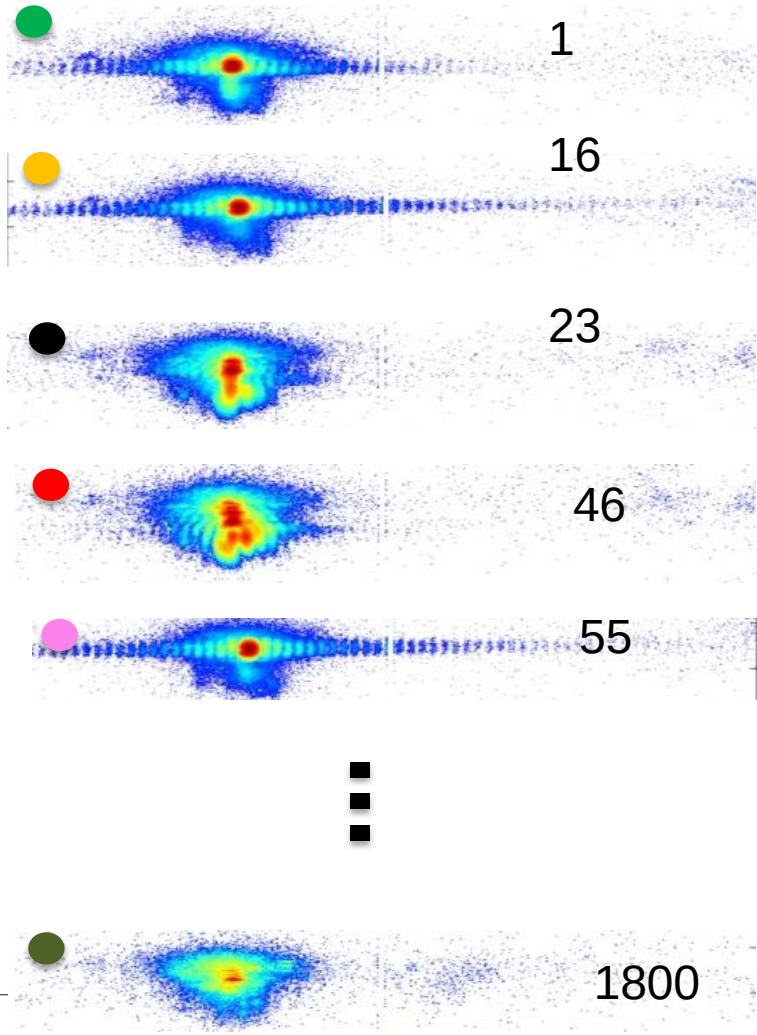




Ptychography: single detector images
GaAs 111



PyNX.Ptycho
J. Appl. Cryst. (2016). 49, 1842–1848



Ptychography reconstructions

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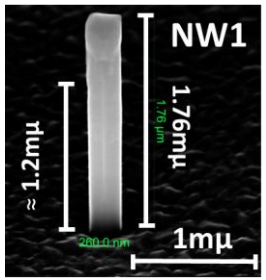
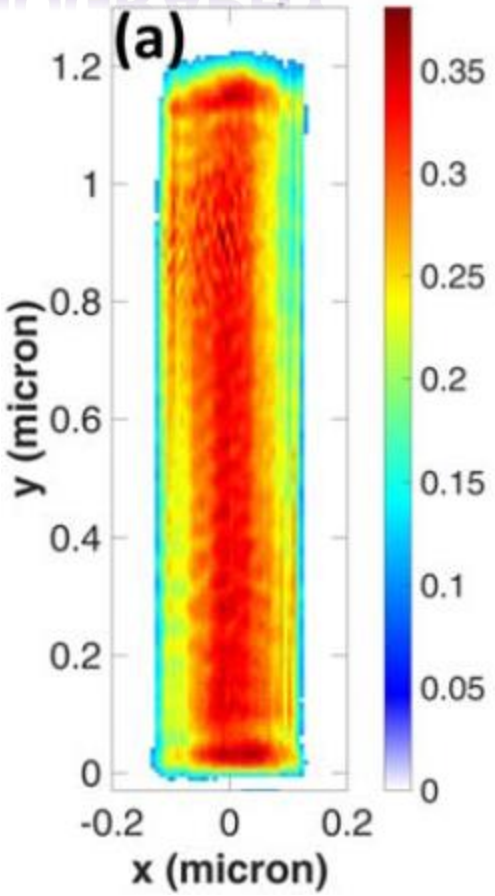
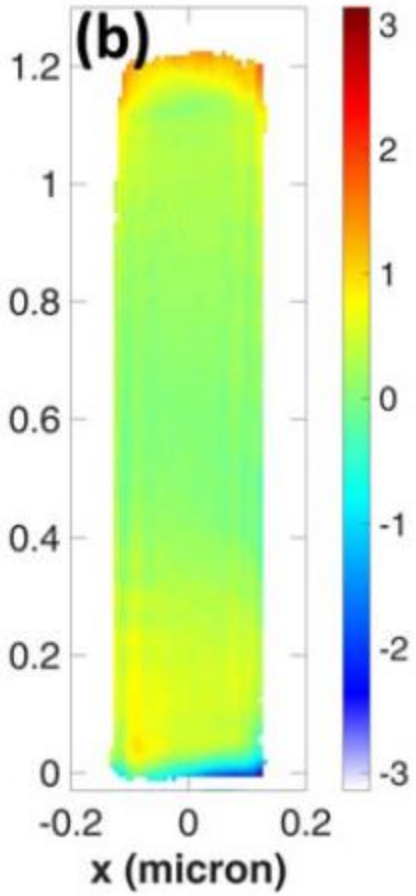
2D PTYCHOGRAPHY

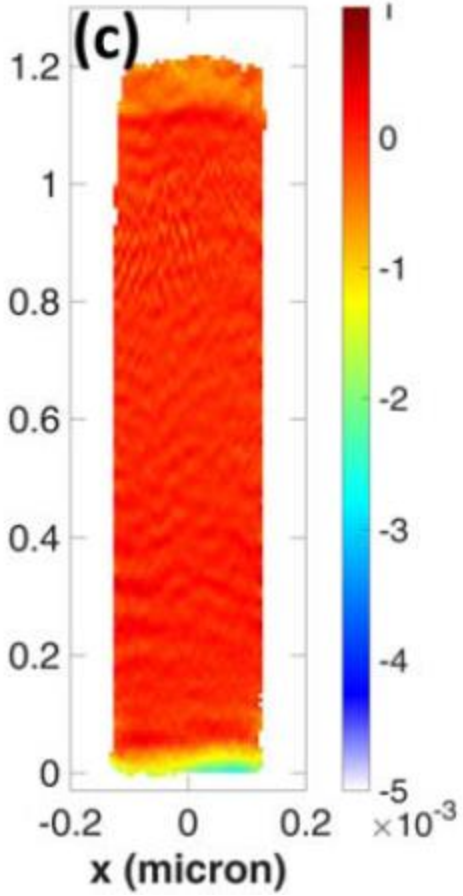




Real space amplitude



Real space phase

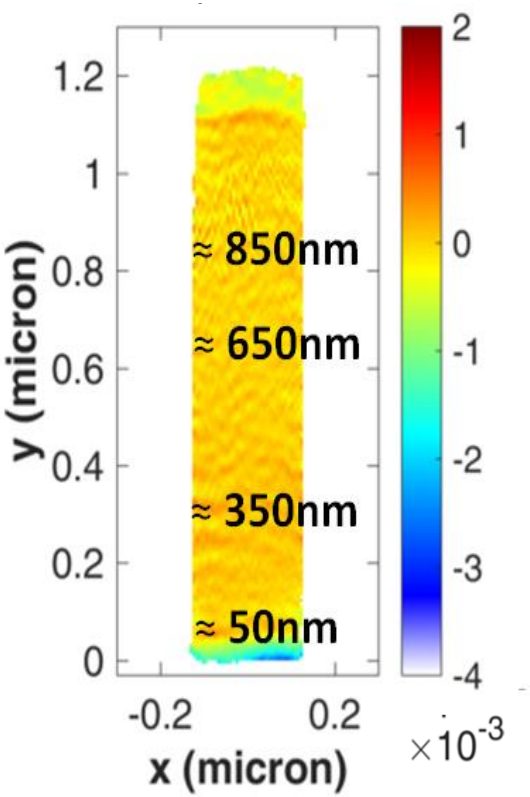


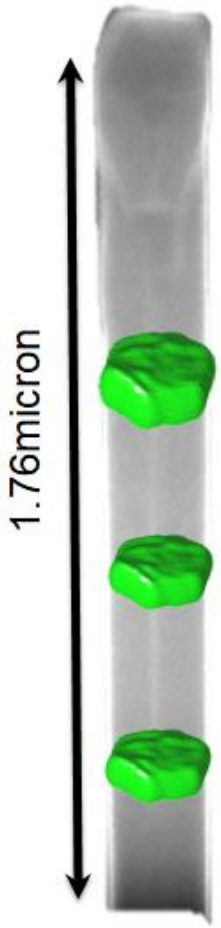
Displacement field

Ptychography and CXDI: **NW1**

Displacement fi

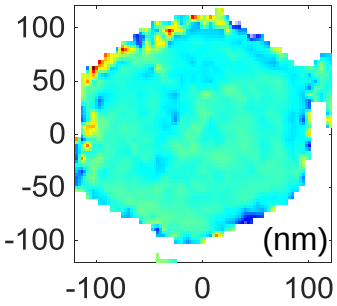
Ptychography



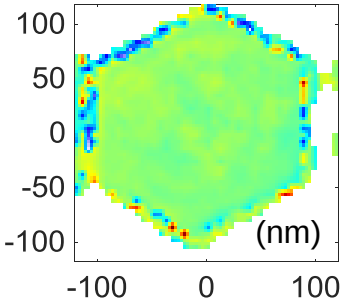


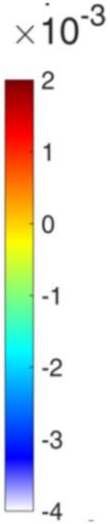
Displacement field (CXDI) NW cross section

≈850nm

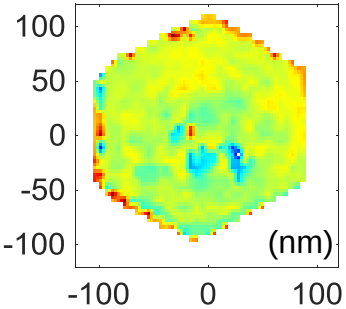


≈550nm





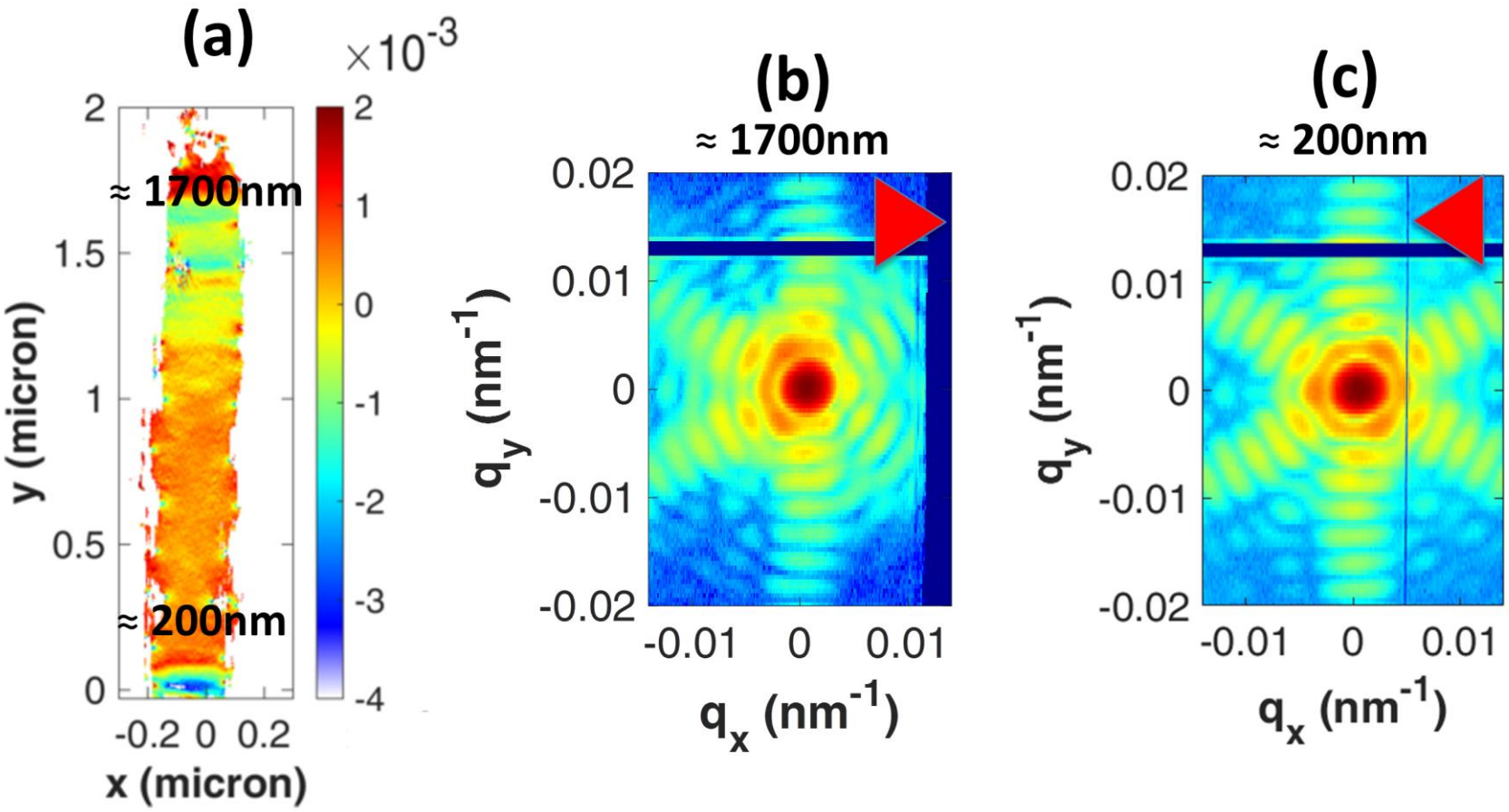
≈350nm



Ptychography reconstruction: **NW2**

Displacement field from 2D ptychography

CXDI shows 180 degree rotation of the symmetry



Discussion

We have demonstrated

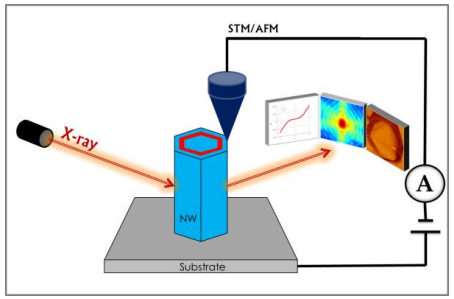
Methodical development of the coherent X-ray diffraction techniques for Imaging strained nanoheterostructures

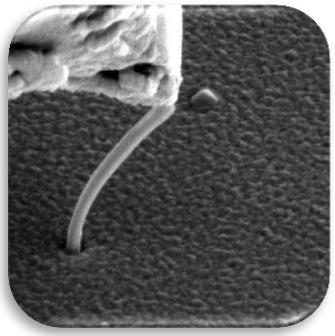
Combination of CXDI and FEM

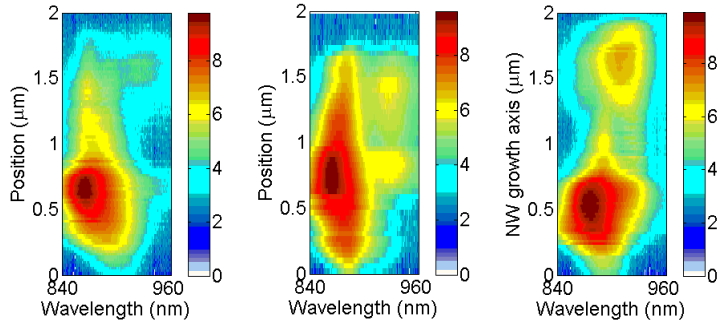
Observation of inhomogeneities in GaAs/InGaAs/GaAs core-shell-shell Nanowire cross section

Combination of CXDI and Ptychography

Characterization of inhomogeneities along the entire nanowire growth axis







Acknowledgements