Towards real-time analysis of morphologies using x-ray scattering

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BERKELEY LAB

U.S. DEPARTMENT OF ENERGY | Office of Science

CAMERA Applied Math

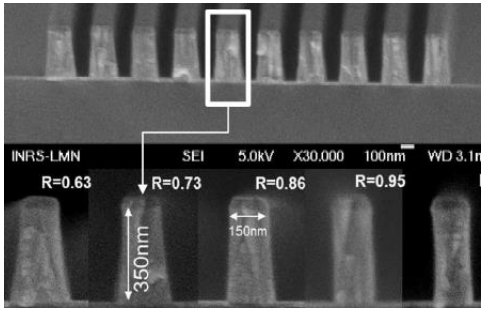
ALS ADVANCED LIGHT SOURCE

Context

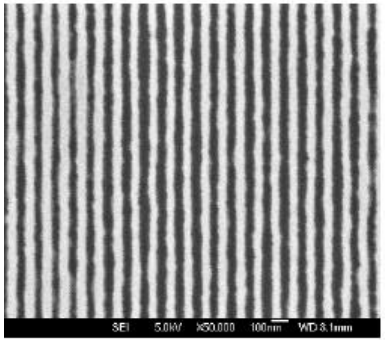
Parameters to control :

- ✓ Pitch
- ✓ Linewidth
- ✓ Line height
- ✓ Roughness
- ✓ Sidewall angle

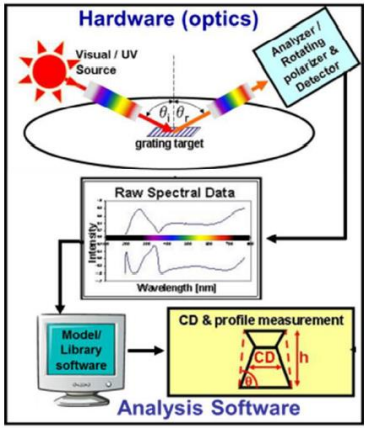
} Sub-nm resolution

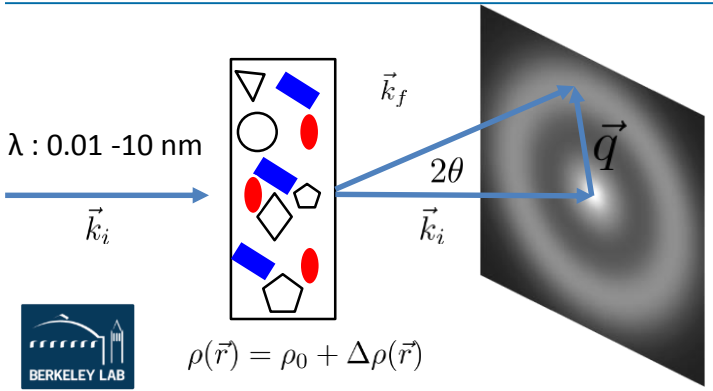


Scanning electron microscopy



OCD (« Optical critical dimension »)





$\rho(\vec{r}) = \rho_0 + \Delta\rho(\vec{r})$

What information can Small Angle X-ray Scattering bring?
How to achieve real time analysis?

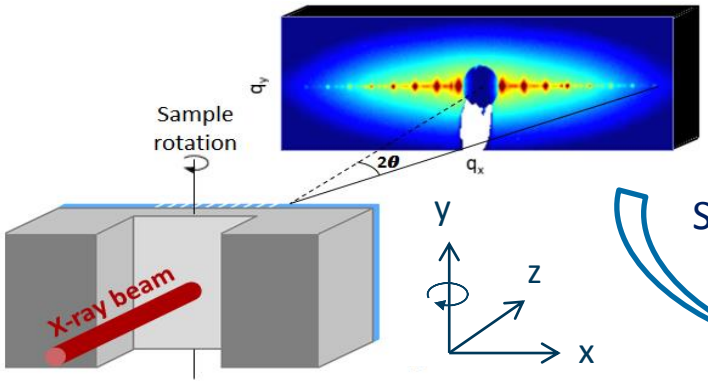
- ✓ Electronic density contrast:
- ✓ 1- 100s nm structure

$$\Delta\rho \sim \Delta n$$

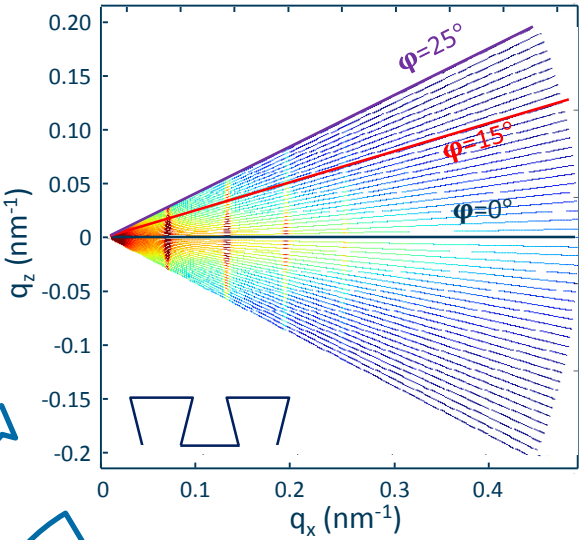
$$n = 1 - \delta + i\beta$$

$$\vec{q} = \vec{k}_f - \vec{k}_i = \frac{4\pi \sin(\theta)}{\lambda}$$

CD-SAXS : principle

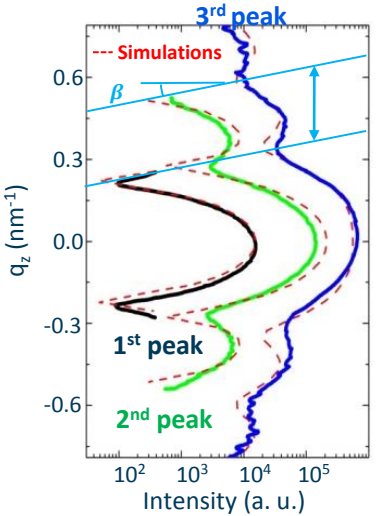


Sample rotation
φ: -25 => 25°



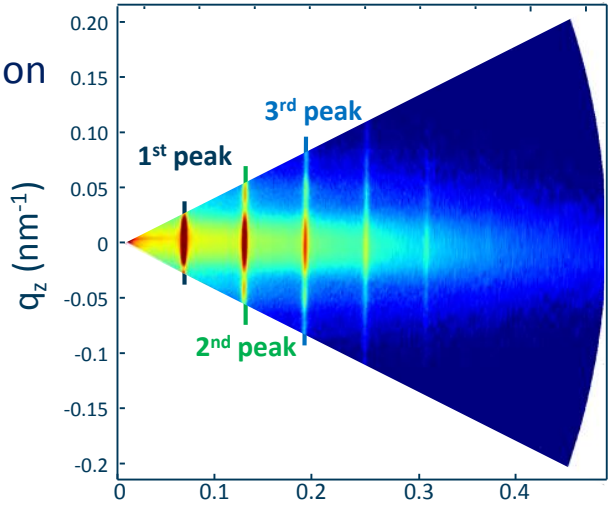
Line profile in xz

Fit the experimental data



Interpolation

1D Vertical cut
(Extraction of the form factor)



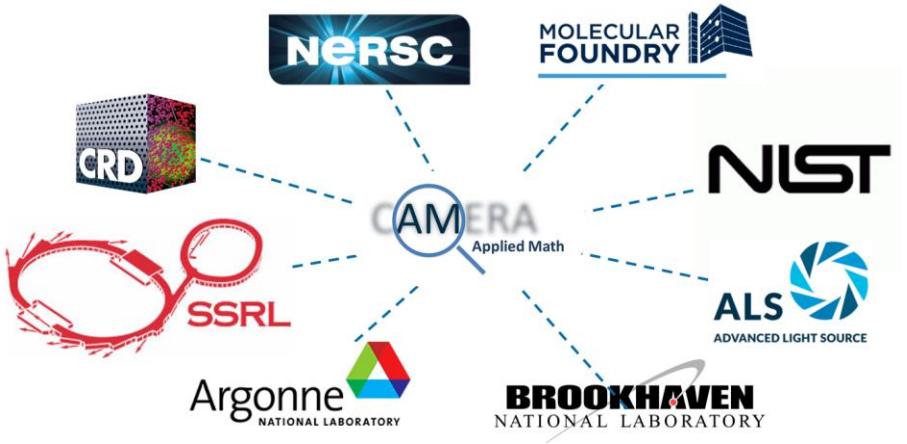
D. Sunday et al. JAC (2015)

Outline

- **High throughput data treatment**
- CD-GISAXS
- Perspectives

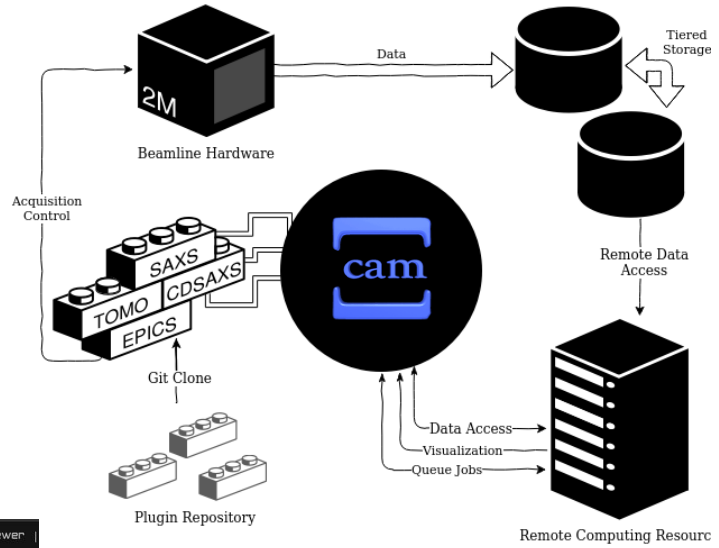
Xi-CAM: High throughput data treatment

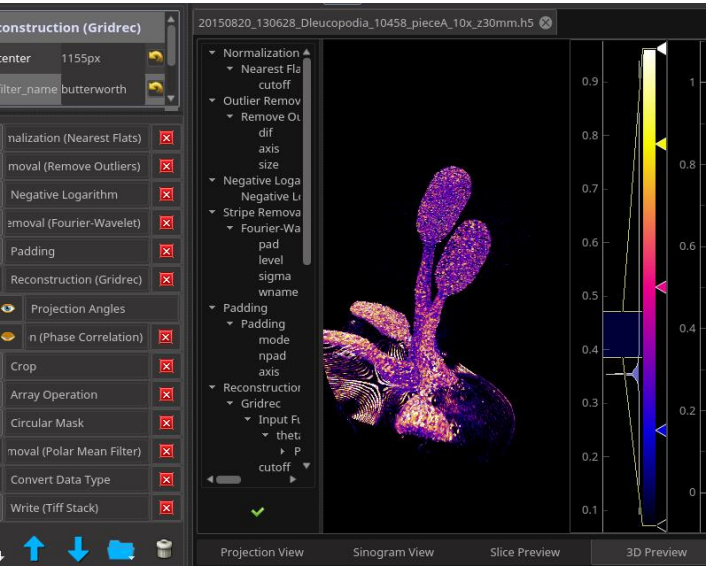
Develop and share data analysis algorithms

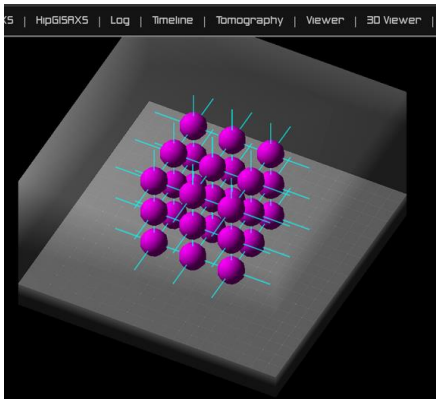


Xi-CAM: High throughput data treatment

- ✓ Xi-CAM as a platform (backend features)
- ✓ Each technique is a plugin!
- ✓ Expose your technique cross-facility
- ✓ Support multi-modal analysis



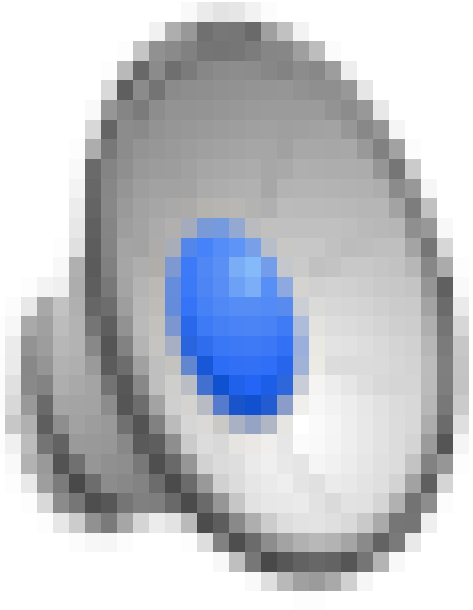




CD-SAXS plugin:

Collaboration with NIST : C. LIMAN, D. SUNDAY, J. KLINE and D. DELONGCHAMPS

Xi-CAM: High throughput data treatment



CD-SAXS limitations

Transmission geometry :

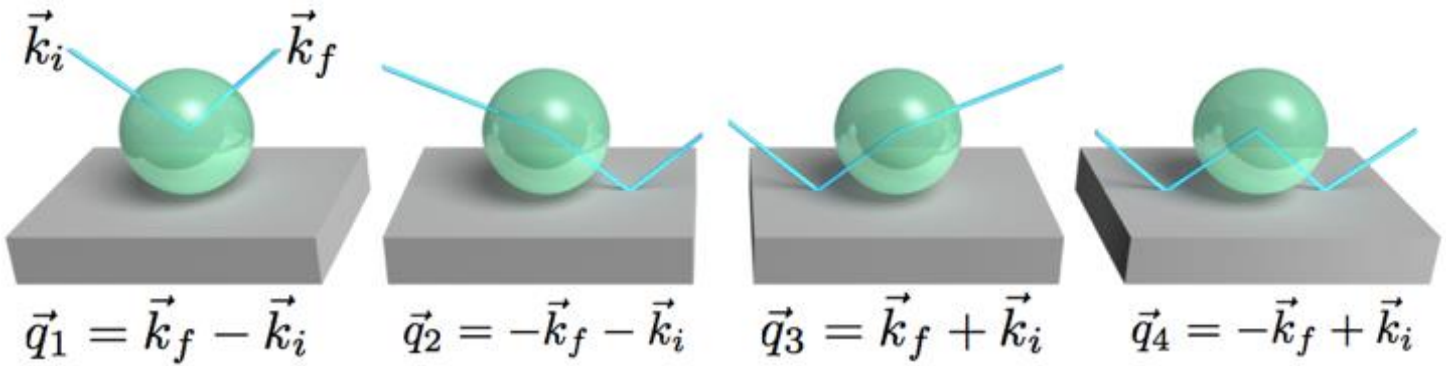
=> Cross the 700 µm silicon wafer:

- ✓ Conventional lab-source (Cu Kα, E = 8.047 keV) : T = 0.01 %
- ✓ High energy lab-source (Liquid Metal Jet, E > 20 keV) : T = 55 %

=> Acquisition time : > 30 minutes

Reflection geometry : GISAXS

Distorted Wave Born Approximation



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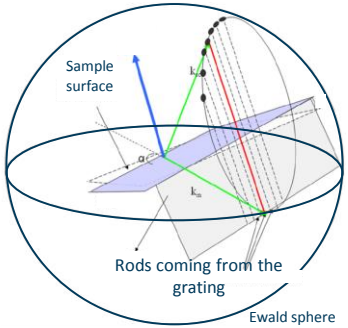
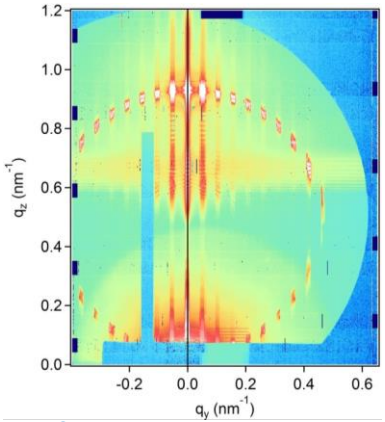
- **CD-GISAXS**
- Perspectives

CD-GISAXS



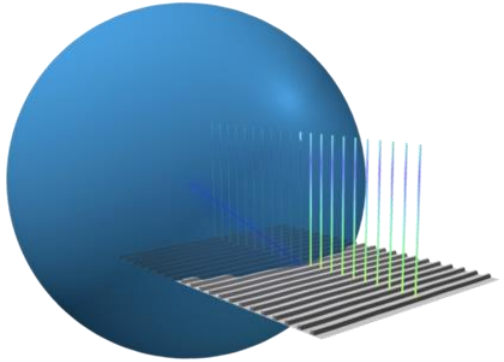


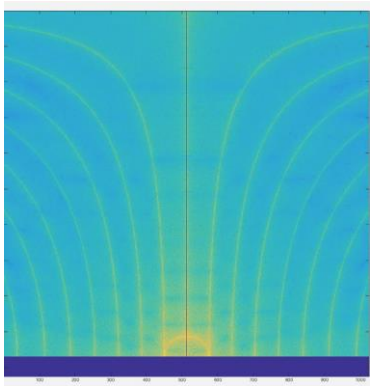
Semi-circle of spots:

Intersection between the Ewald sphere and the Bragg rods coming from the grating

Probing the form factor only at few q values

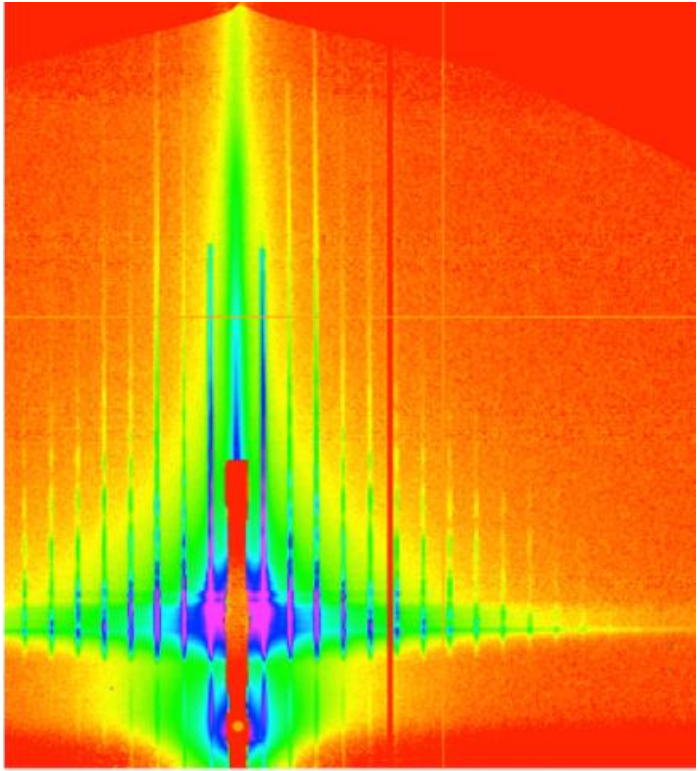
Rotation of the sample

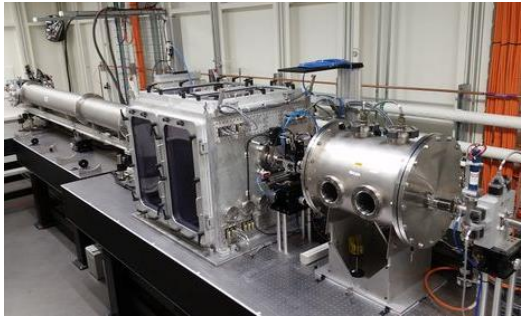




Intersection of the Ewald sphere probing the full Bragg rods

CD-GISAXS

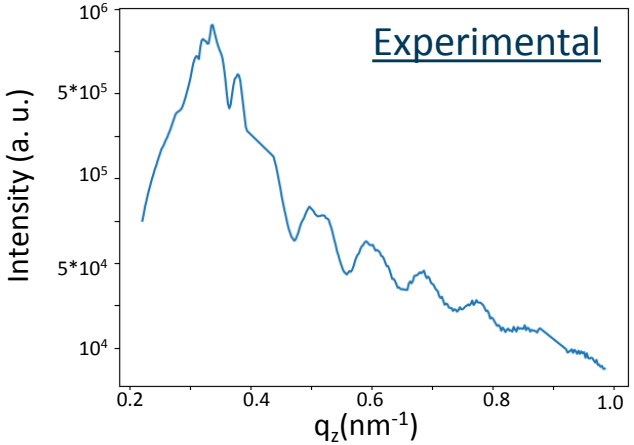


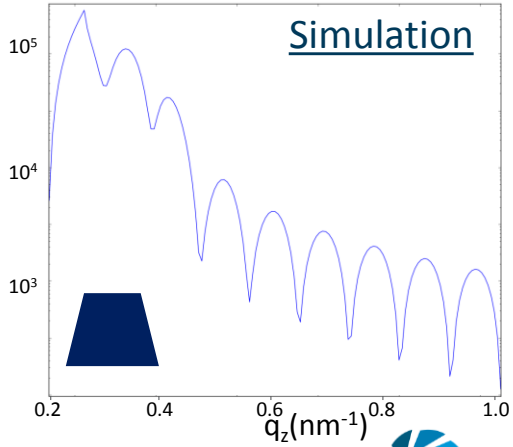


NSLS-II 11-BM CMS Complex Materials Scattering

(M. FUKUTO, K. YAEGER)

7.3.3 beamline (ALS)





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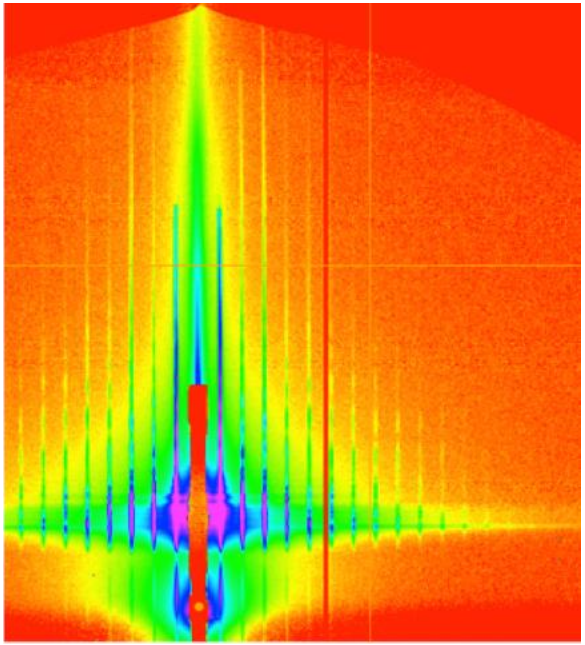
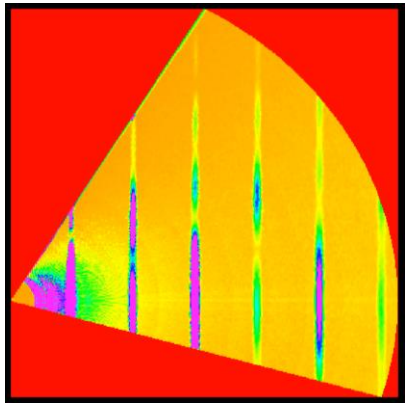
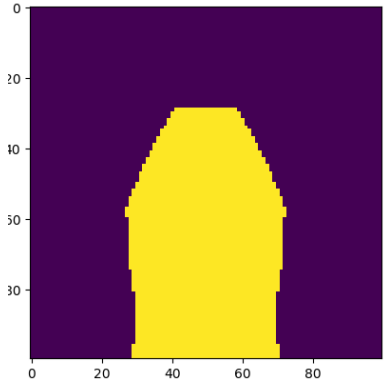
Combination of CD-GISAXS and CD-SAXS



CD-SAXS





Fitting modulations along Bragg rods
(Multi-trapezoid stack)

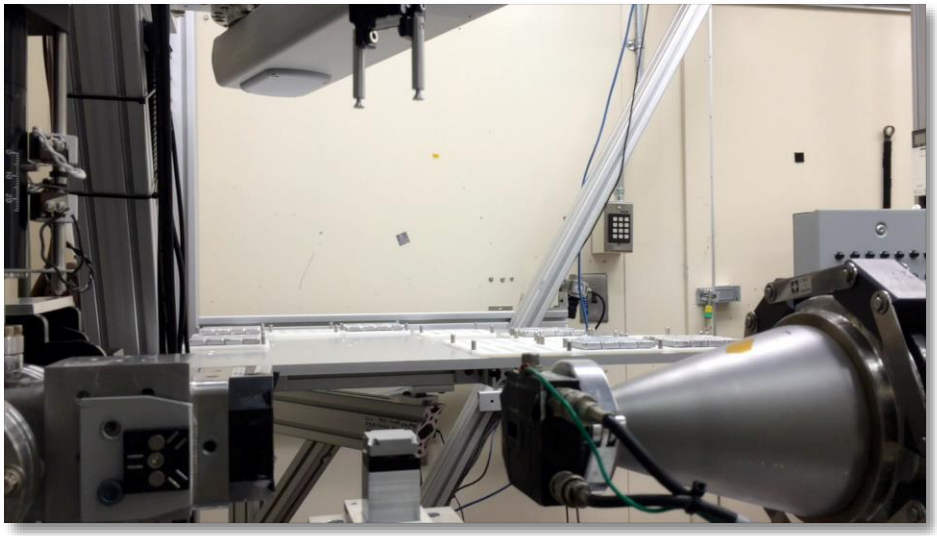
Combination of profiles extracted by both techniques will increase the accuracy and confidence on the model

CD-GISAXS: High throughput measurement

Automation of he measurement on 7.3.3 beamline at the ALS

- Robotic arm to change the samples
- 30 seconds measurements
- Several orders => fit more precise

Fit the data on the fly (during the positioning of the new sample)



CD-GISAXS at the lab

- “Low energy source” => conventional Cu-Kα
- Simulations running on a classic computer
- A precise rotational stage is needed

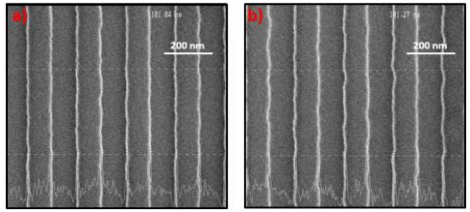
Outline

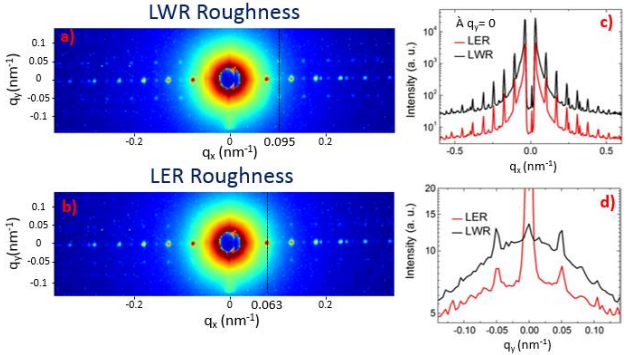
- High throughput data treatment
- CD-GISAXS
- **Perspectives**

Perspectives

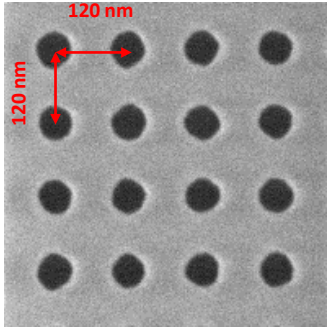
- ✓ Study of line roughness
CD-SAXS on periodic roughness

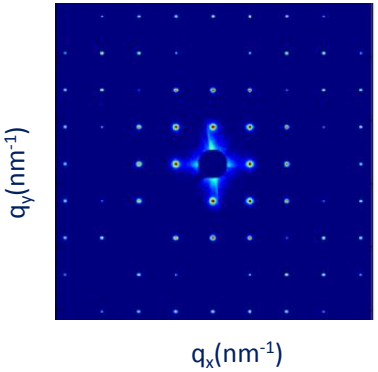
- ✓ Combination of CD-SAXS/GISAXS for LER/LWR roughness

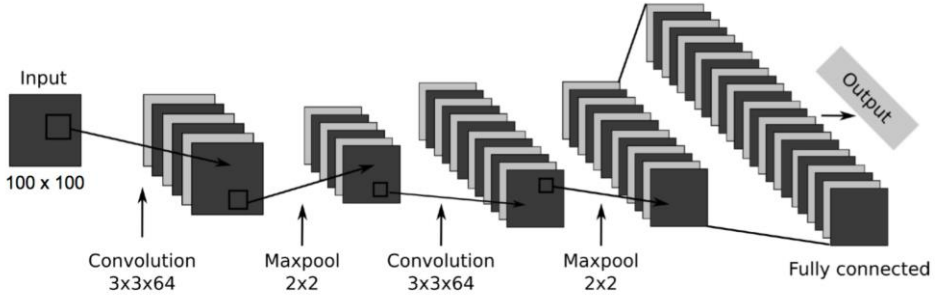




- ✓ 2D gratings of cylinders
(Collaboration with NIST and CEA Grenoble)







- ✓ Machine learning (Convolutional Neural Network)
Classification of the data and automatic pre-treatment

Acknowledgements

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CAMERA

Thank you for your attention!


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