The Impact of Latent Imaging of Resists via Grazing Incidence Resonant X-ray Scattering

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BERKELEY LAB

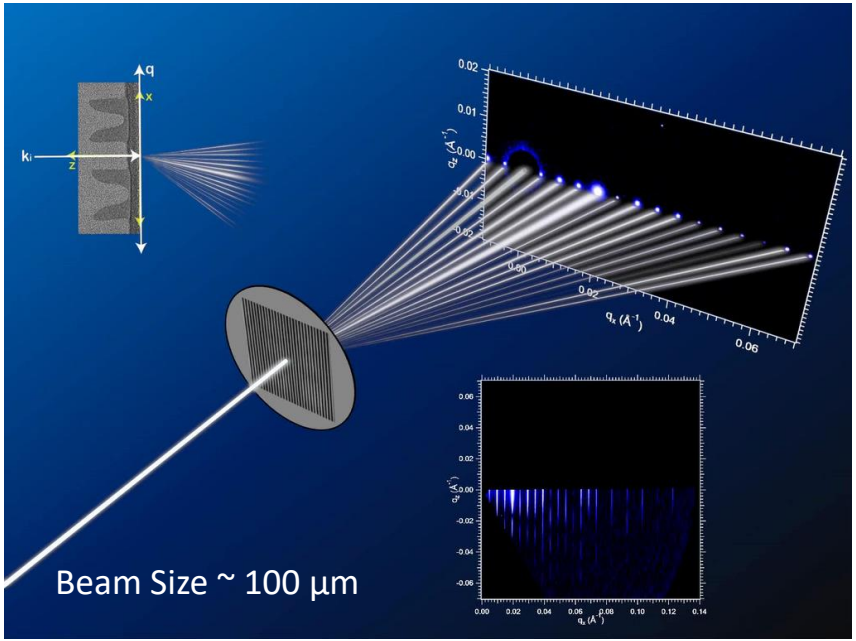
OUTLINE

1. Resonant Scattering (ReXS) for Semiconductors
2. Impact of Grazing Incidence CD-ReXS
3. Summary and Outlook

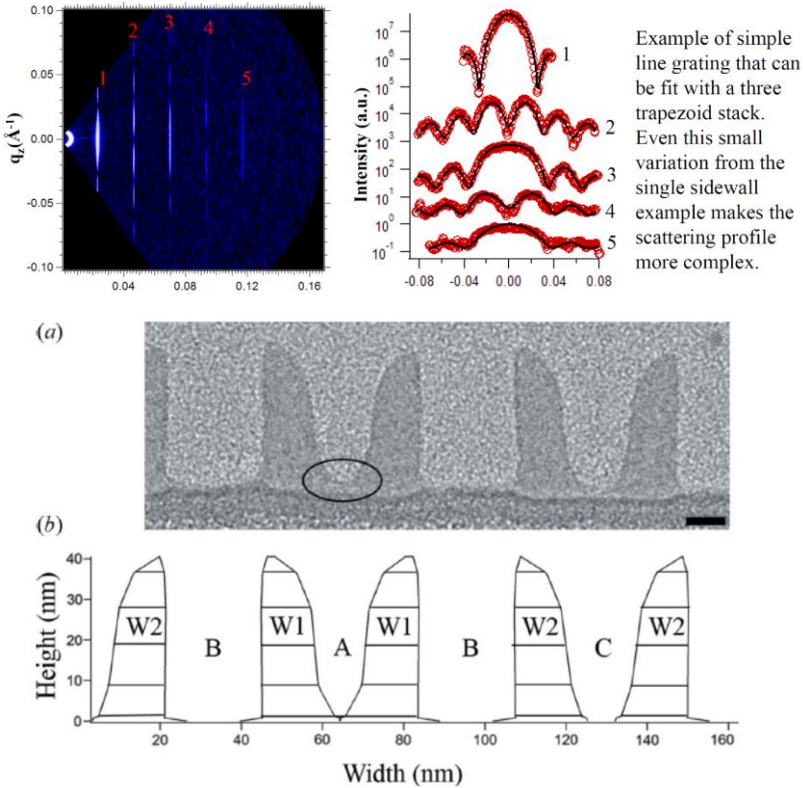
1st Key Enabling Development

Reconstructing 3D Profiles from CD-SAXS

CD – Small Angle X-Ray Scattering (SAXS)



Credit: RJ Kline, D Sunday, D Delongchamp, NIST

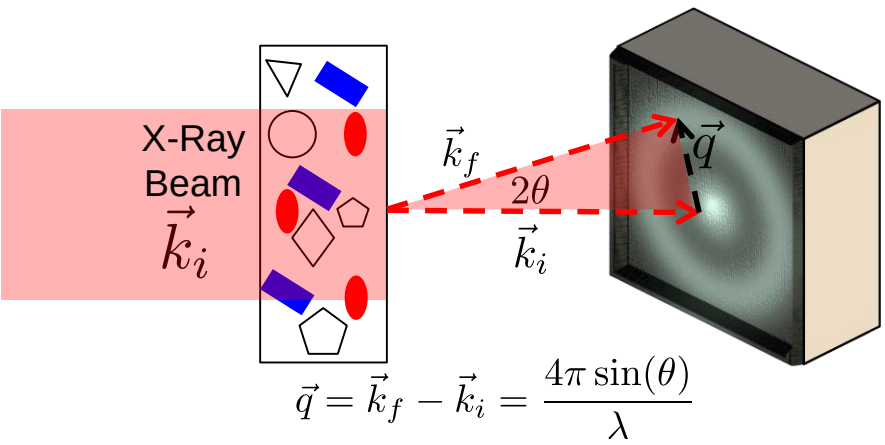


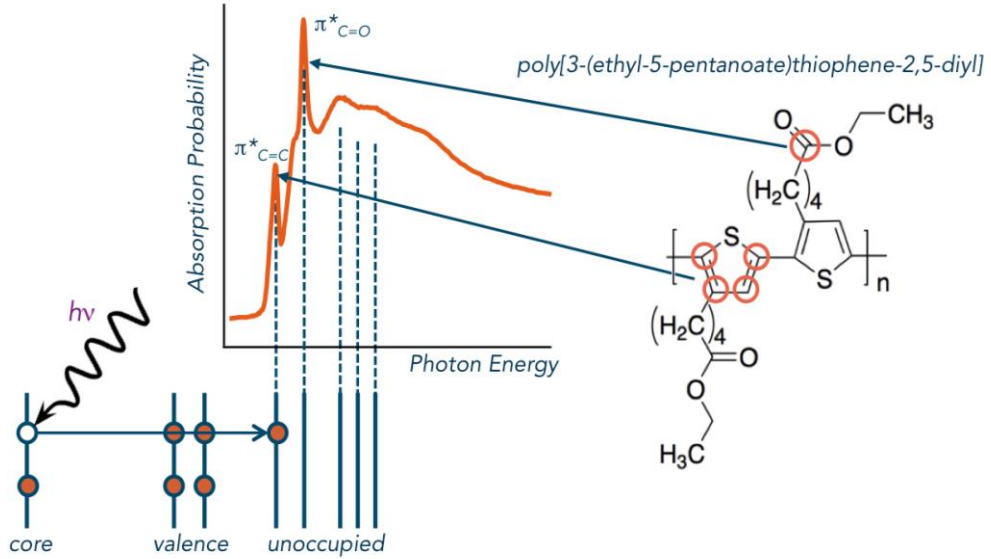
Example of simple line grating that can be fit with a three trapezoid stack. Even this small variation from the single sidewall example makes the scattering profile more complex.

Ref: Sunday et al, J. Appl. Cryst., 48, **2015**

Resonant **So**ft **X**-Ray **S**cattering (**RSoXS**)

Small Angle X-Ray Scattering + X-ray Absorption Spectroscopy (β)

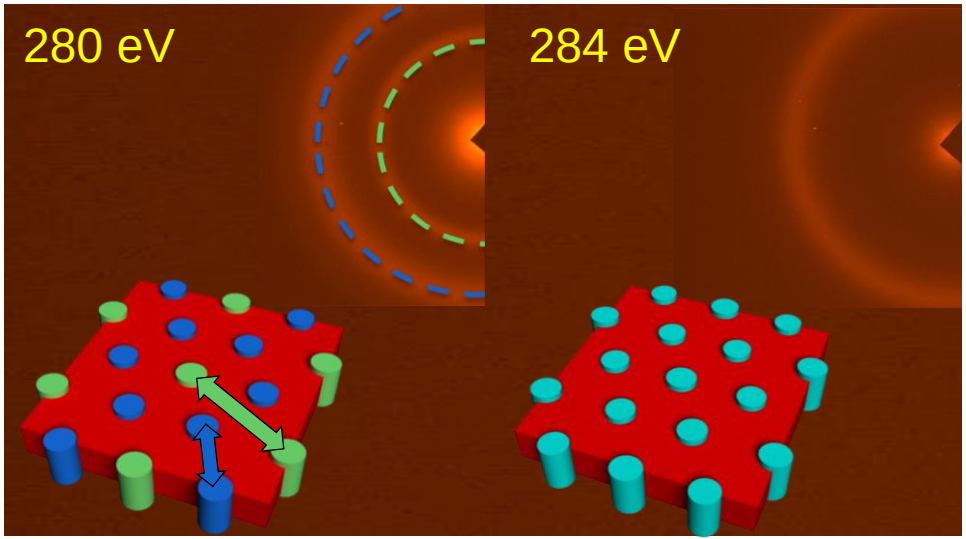




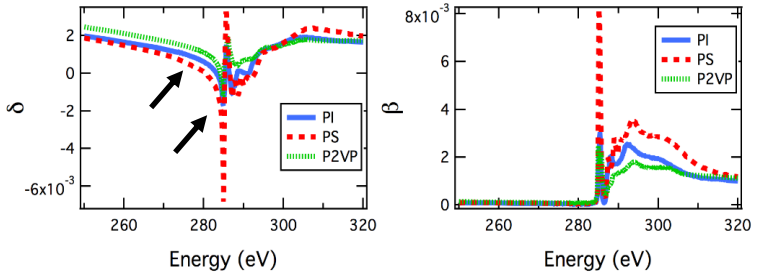
Refractive Index
$n(E) = 1 - \delta + i\beta$

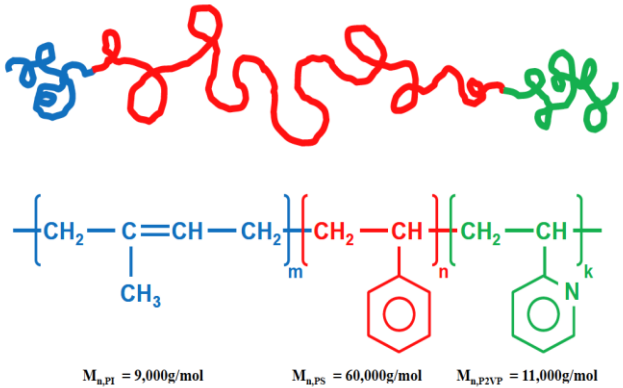
Scattering Intensity
$I(q) \alpha |\Delta n|^2 = |\Delta\delta^2 + \Delta\beta^2|E^4$

RSoXS as a Spatiochemical Probe

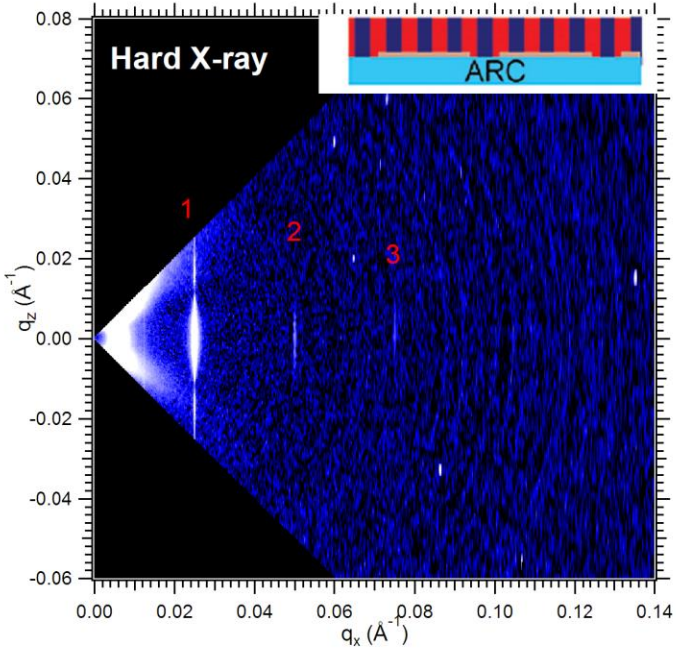


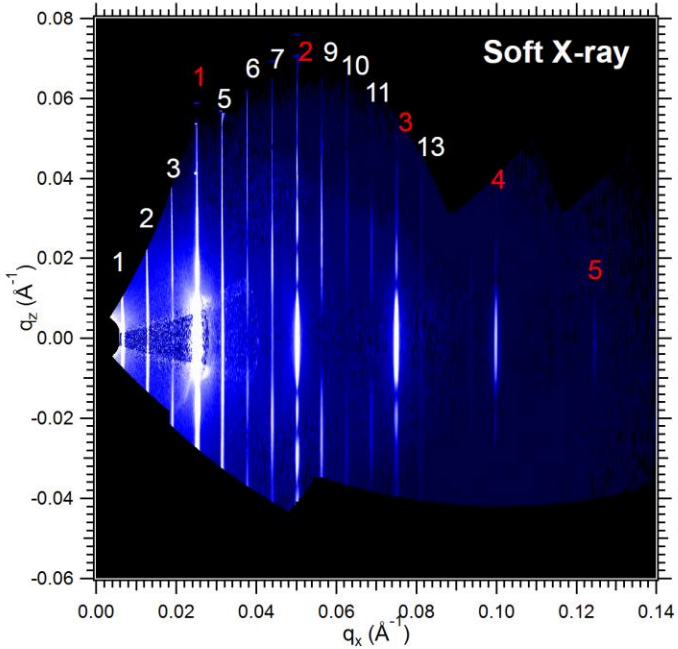
Credit: C. Wang *et al*, *Nano Lett.*, **2011**, 11, 3906





Transmission CD-RSoXS on PS:PMMA BCP



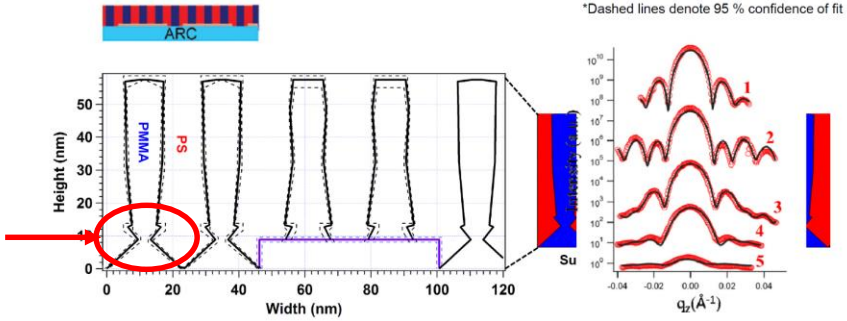


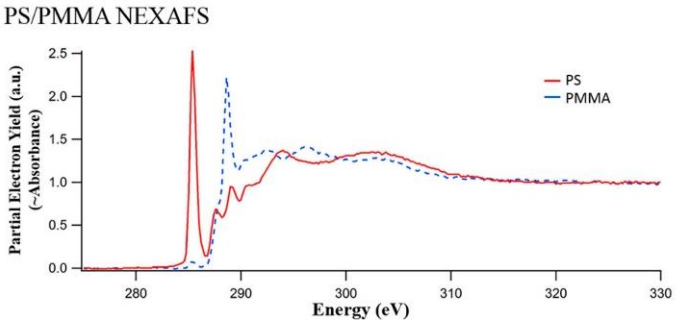
Sunday et al. **ACS Nano** 8 (8), 2014, 8426

Transmission CD-RSoXS on PS:PMMA BCP

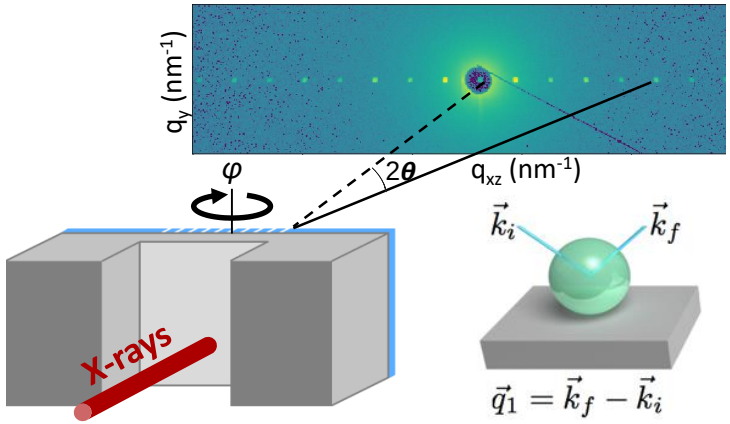
- Advantages
  - ➢Chemical sensitivity
  - ➢Probes buried structures with sub-nm sensitivity

- Fundamental Limitation
  - XSoft x-rays cannot penetrate silicon wafer





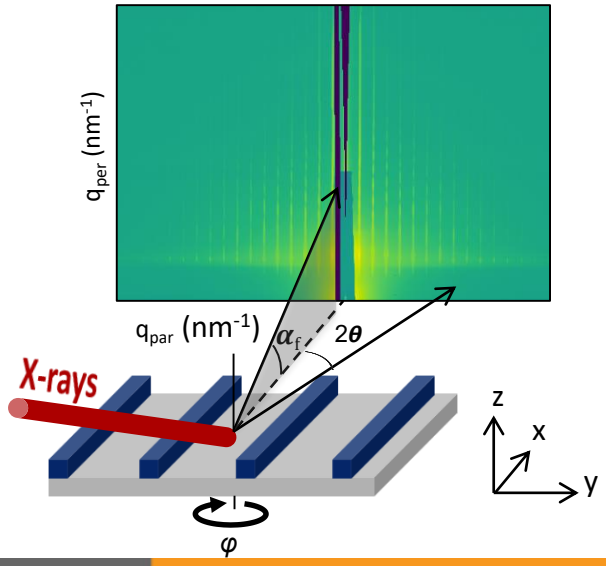
Sunday et al. **ACS Nano** 8 (8), 2014, 8426



Transmission SAXS

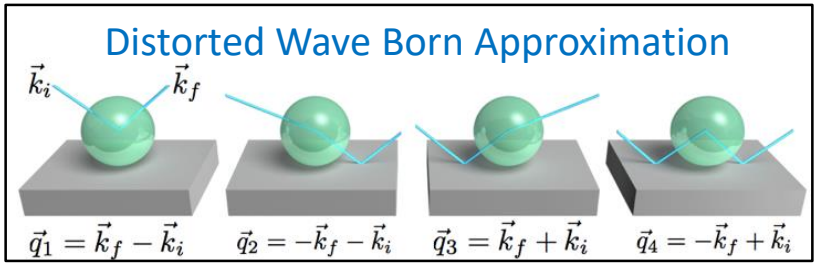
- High energy x-ray source
- Back-etching wafers
- Samples on X-ray membrane windows
- "Easy" modeling *via* Born Approximation

D. F. Sunday et al., ACS Appl. Mater. Interfaces (2017)



Grazing-incidence SAXS (GISAXS)

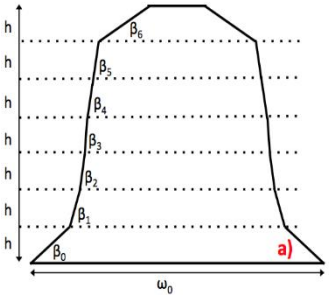
- ✓ Reflection mode (angle function of material and λ_{inc})
- ✓ Probe thin films **on Silicon wafer (e.g., 700 µm)**

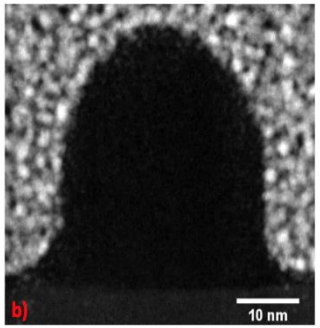


2nd Key Enabling Development

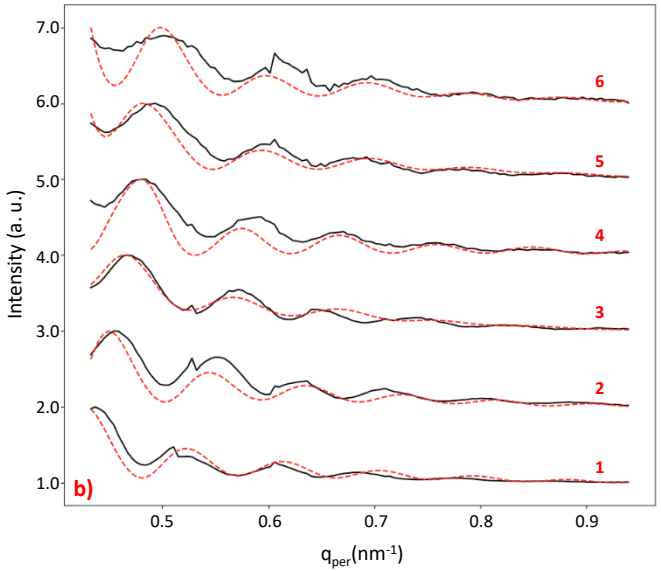
DWB-Compatible Analytical Model for CD-GISAXS

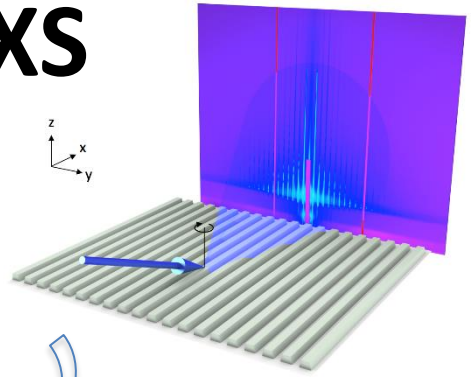
Critical-Dimension GISAXS





Fit using genetic algorithm





1D vertical cut

Ref: G. Freychet and D. Kumar *et al*, Manuscript Submitted

Good agreement between the cross-section TEM and the CD-GISAXS!

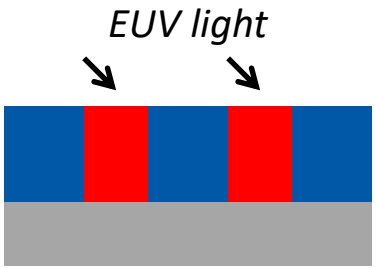
3rd Key Enabling Development

Increasing Scattering Contrast of exposed resists *via* CD-GIREXS

Goals for Undeveloped EUV Resists

1) Extract the 3D line shape of latent image

2) Compare with developed results to test predictability



Commercial EUV Chemically Amplified Resist (CAR):

EUV exposure and PEB leads to chain scission

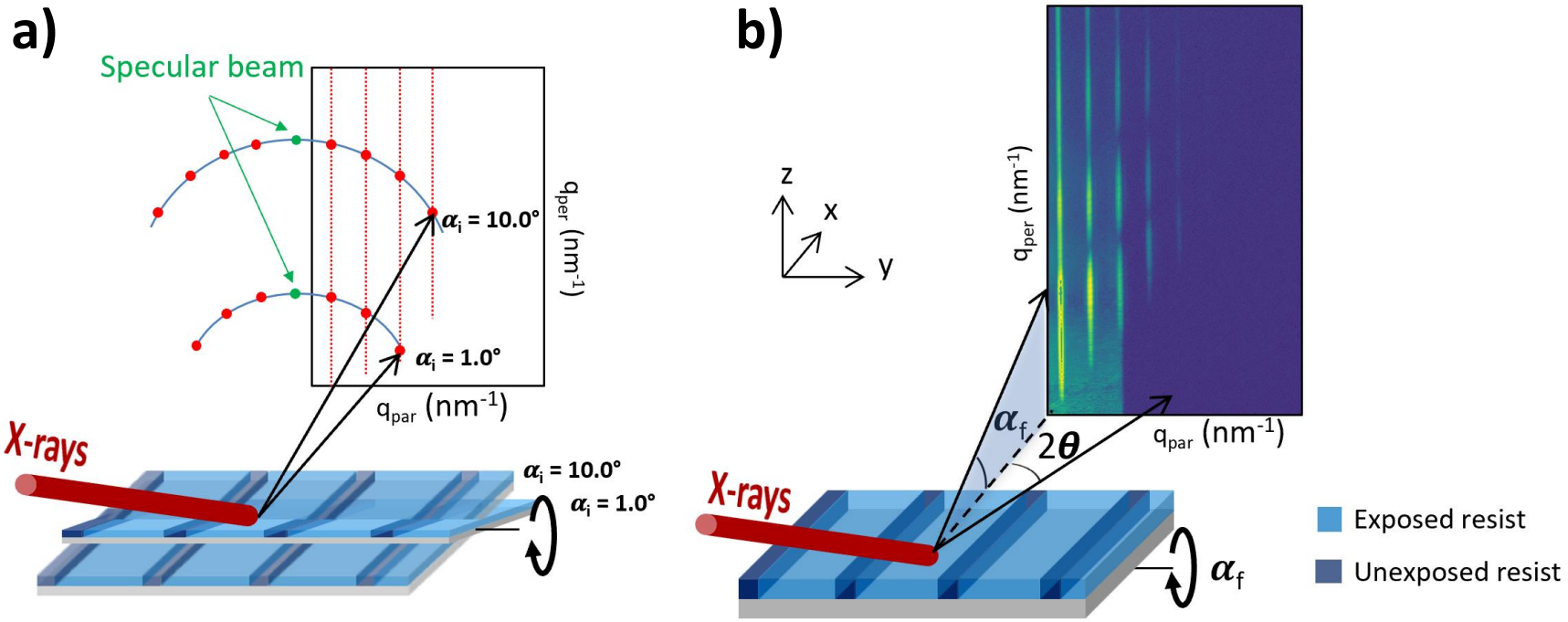
⇩

Very low electronic density contrast between the exposed and unexposed regions of resist…

⇩

Can we leverage any intrinsic chemical contrast??

Experimental Configuration

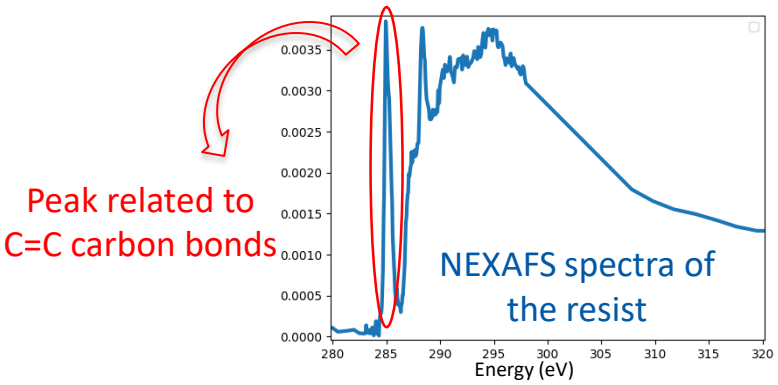


Latent Image of CAR *via* CD-GIRSOXS

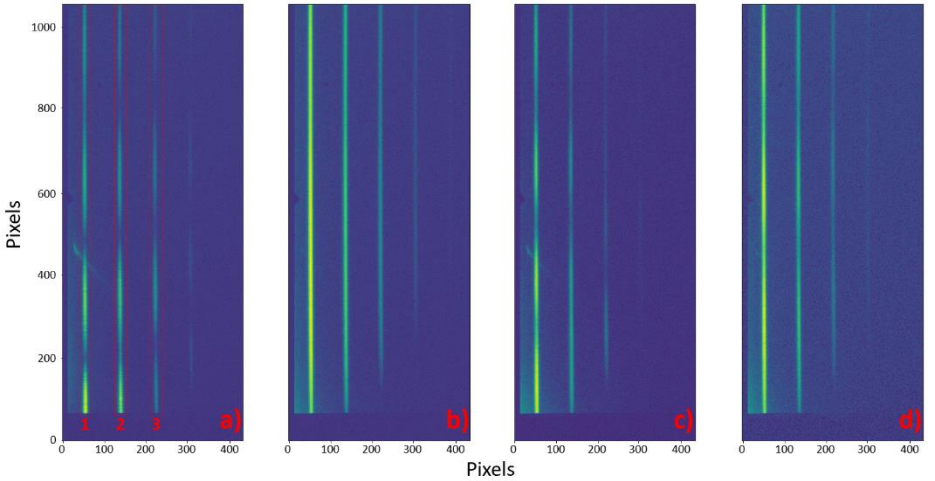
- ✓ Exposure with E-beam lithography
  - ✓ 200 nm pitch line gratings
    - ✓ Post-Exposure baking

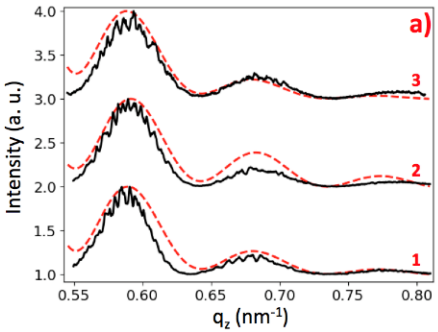
Exposure + bake:
Chain scission

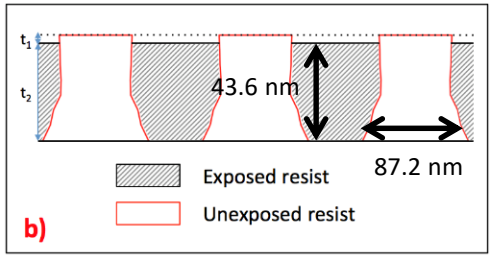
Modification of the carbon environment
→ Modification of the β and δ
→ Introduction of a scattering contrast



G. Freychet & I. Cordova et al, *J. Micro/Nanolith.*, 024003 (2019)

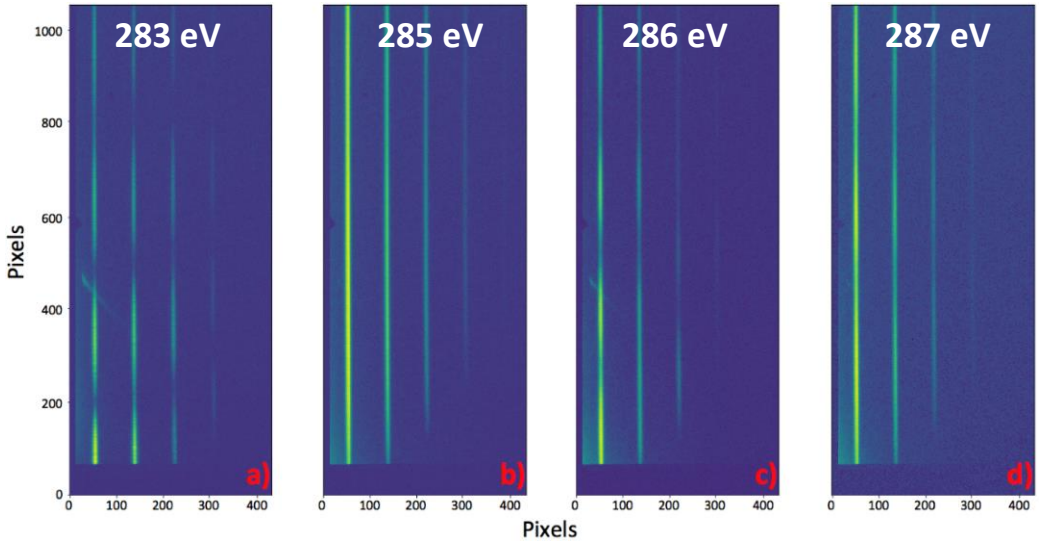


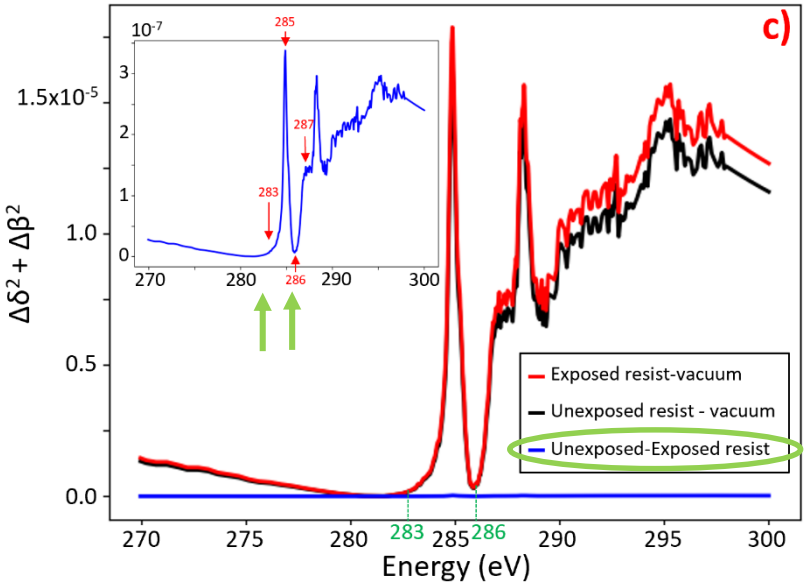




*Covariance matrix adaptation evolutionary strategy (CMAES)

Origin of Resonant Contrast

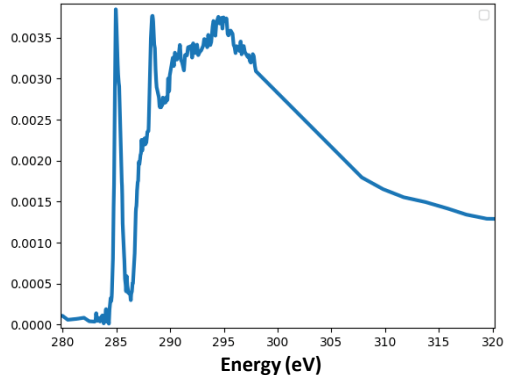




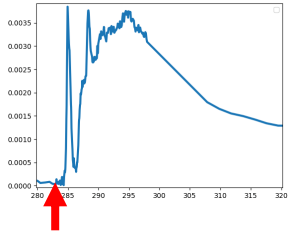
G. Freychet & I. Cordova et al, *J. Micro/Nanolith.*, 024003 (2019)

Assessing the impact of latent imaging

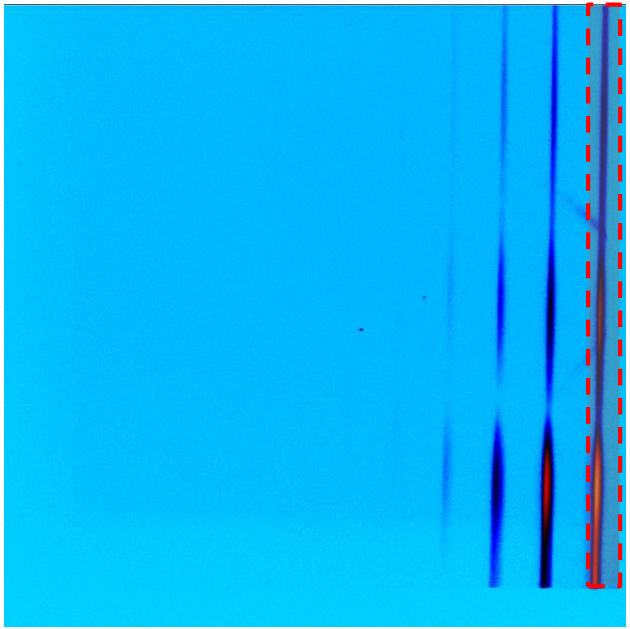
Beam damage on CAR when measuring at the Carbon edge



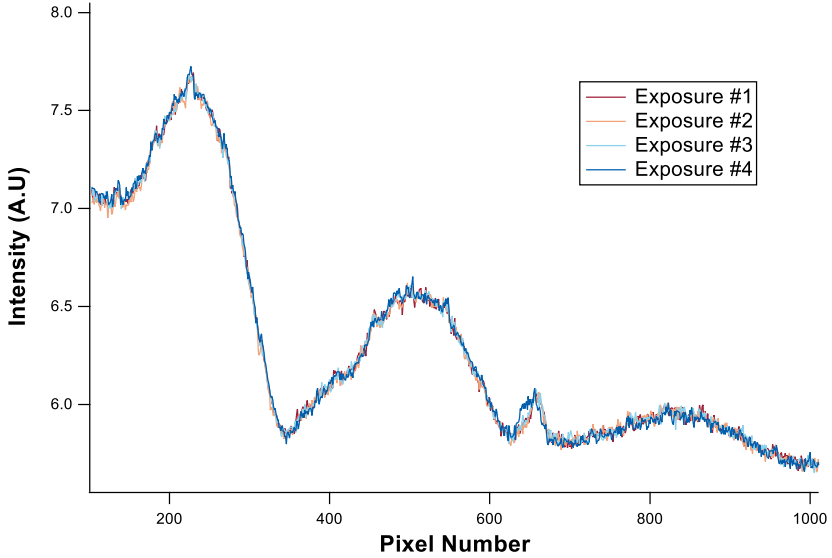
CAR Damage during Latent Imaging



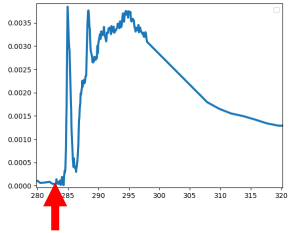
Scattering at 283 eV



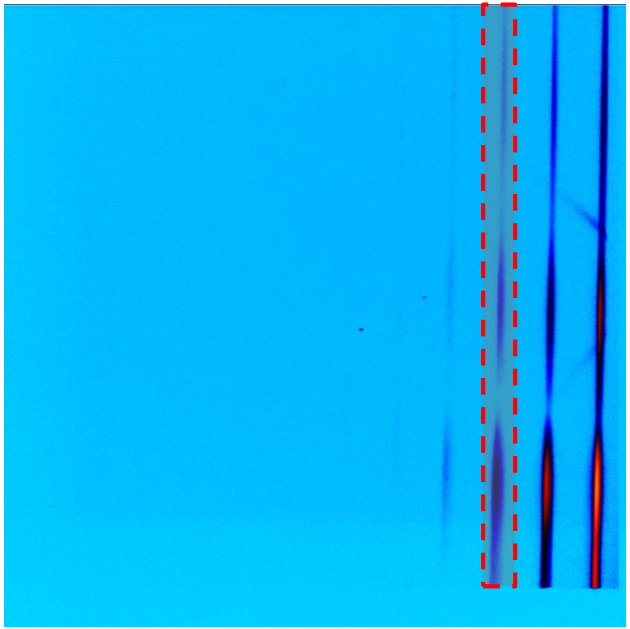
1st Order @ 283 eV



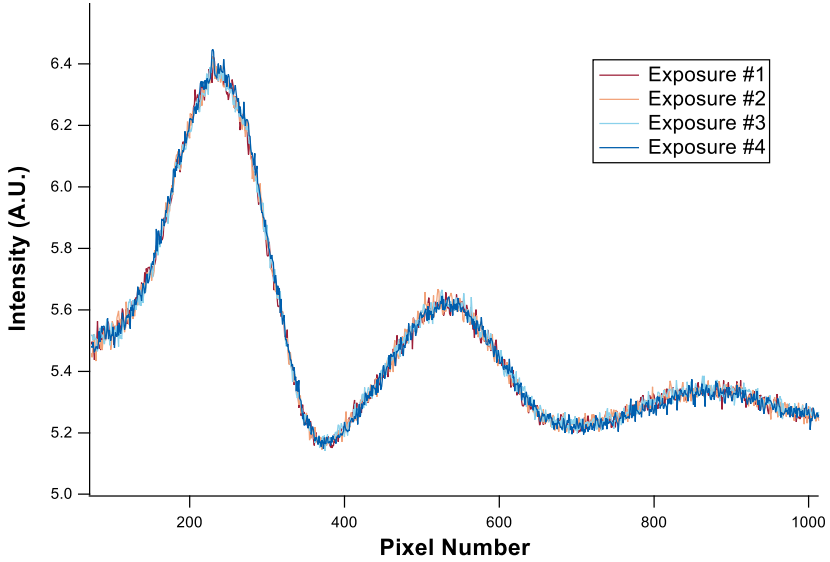
CAR Damage during Latent Imaging



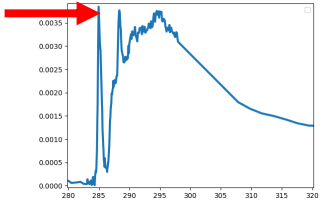
Scattering at 283 eV



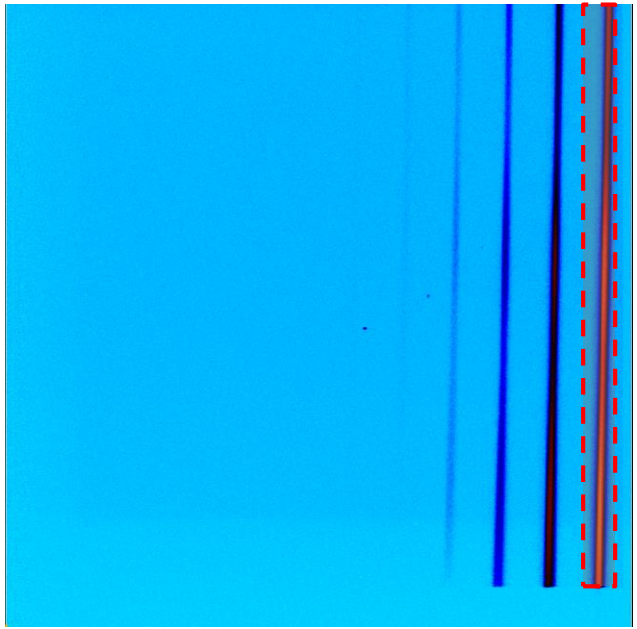
3rd Order @ 283 eV



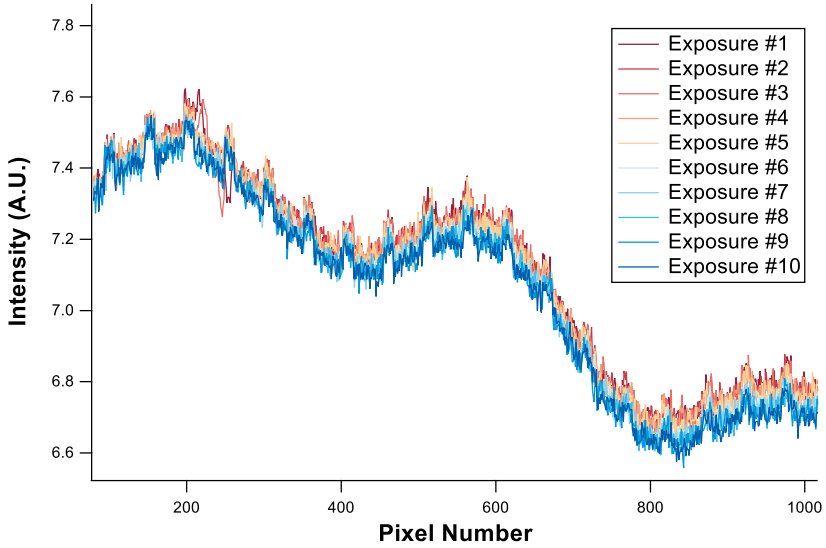
CAR Damage during Latent Imaging



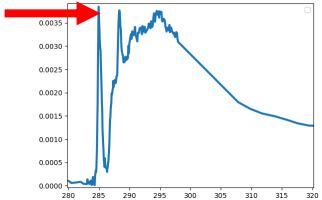
Scattering at 285.2 eV



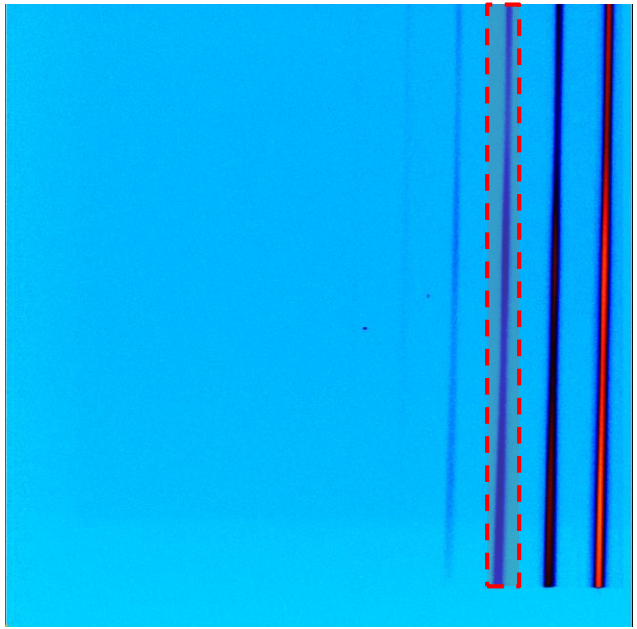
1st Order @ 285.2 eV



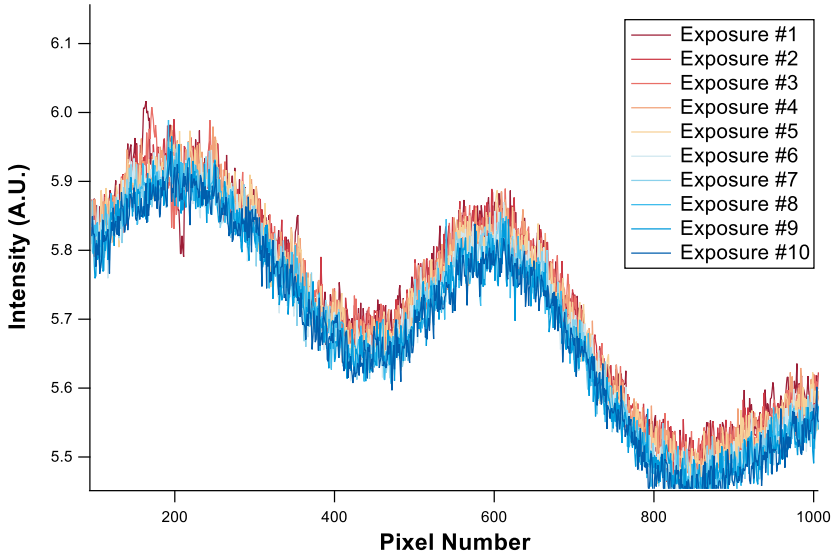
CAR Damage during Latent Imaging



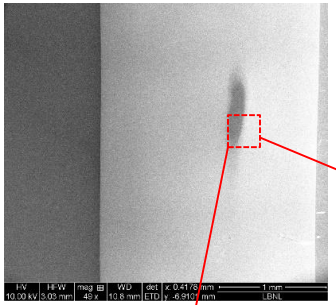
Scattering at 285.2 eV

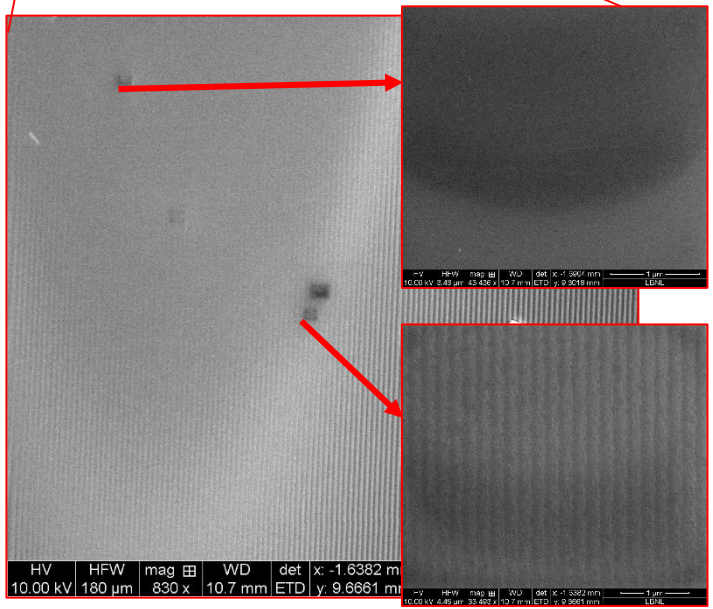


3rd Order @ 285.2 eV

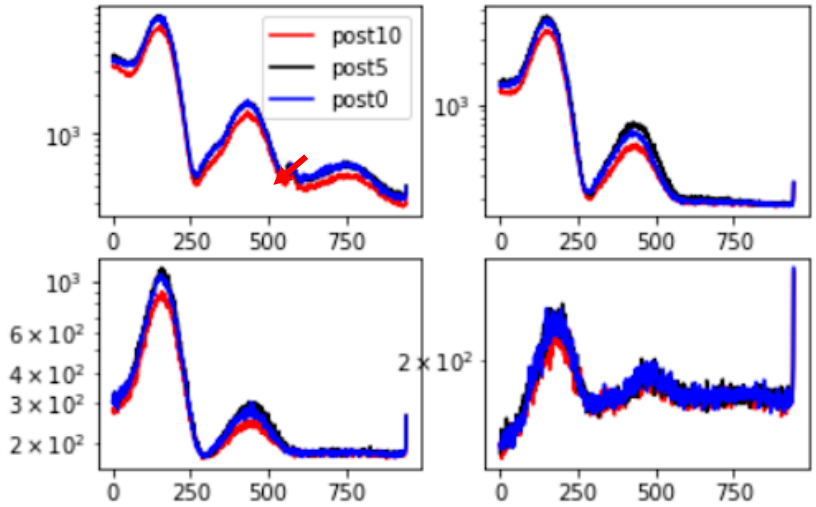


Beam Damage due to 285.2 eV

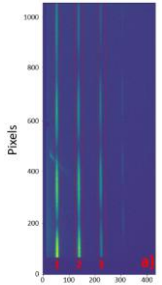




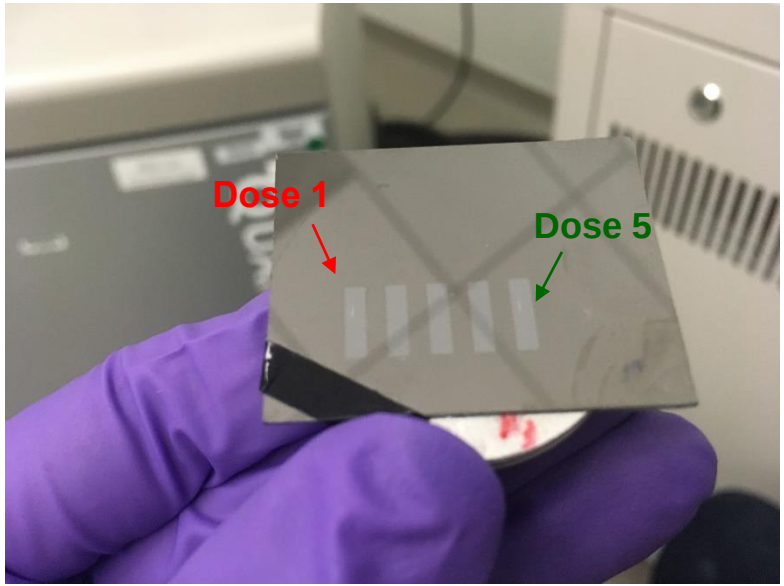
Tracking Effects w/ 283 eV



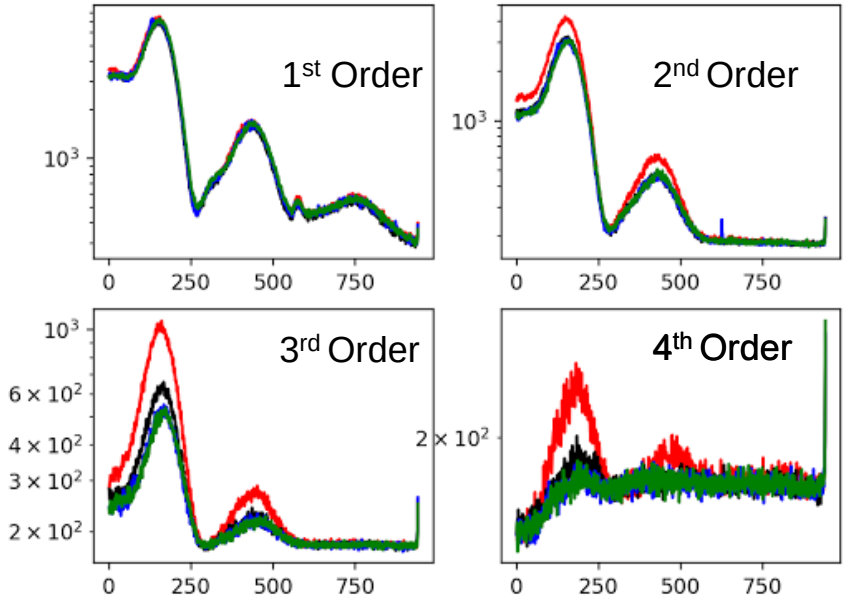
Can we predict dosing effects?



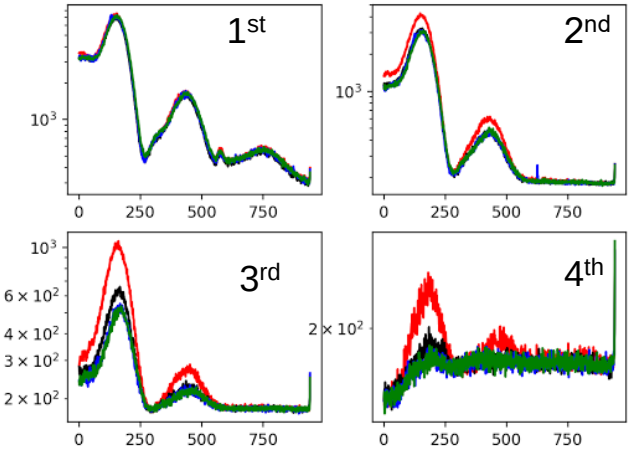
10% Steps in E-Beam Dosing



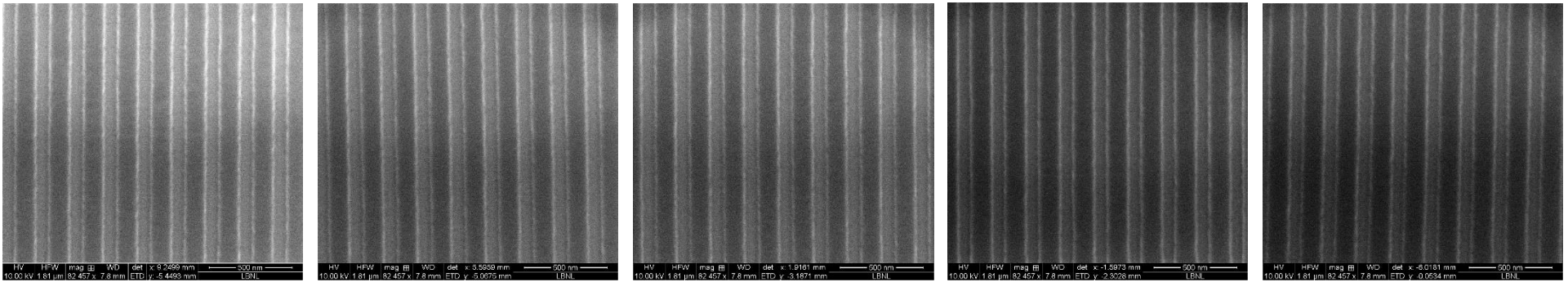
Scattering Orders across Doses



Comparison with Developed Structure



Dose 1 | Dose 2 | Dose 3 | Dose 4 | Dose 5



Increasing Linewidth (Roughness?)

Summary and Outlook

Conclusions

- Successfully applied RSoXS (REXS) to CD-GISAXS
- Acquired latent image profile of commercial CAR EUV
- Minimal beam damage at resonance just below Carbon edge
- Potentially able to predict significant changes in final structure

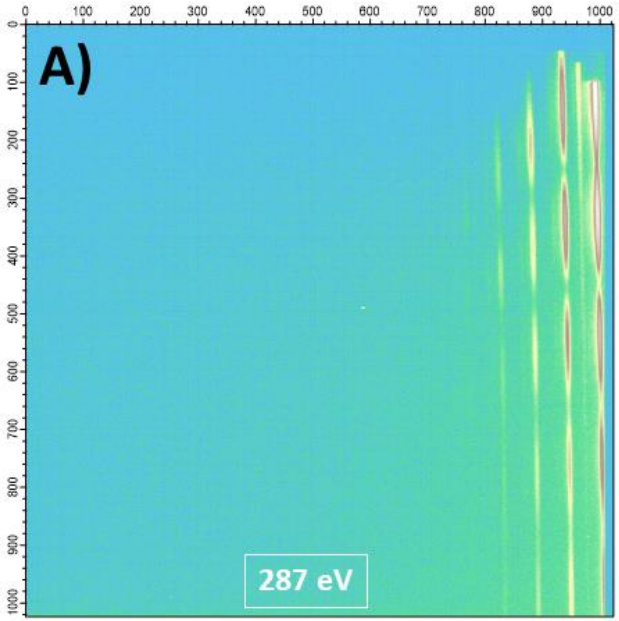
Ongoing Work

- Quantify LER/LWR predictions
- Verify measurements with CD-SEM and TEM
- Optimization of signal vs. damage (motor movements, detectors, etc)
- In-situ baking measurements…
- Test method for interface/chemical gradient sensitivity

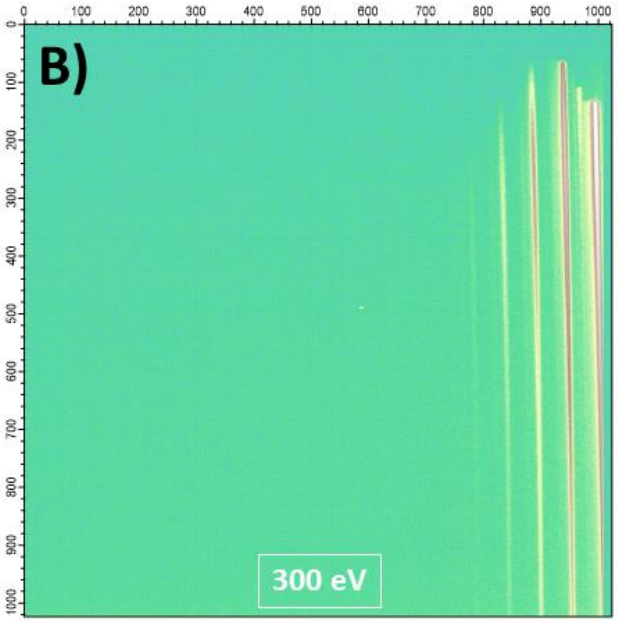
FUTURE PERSPECTIVES

Applying to PMMA, HSQ, MORs, etc…

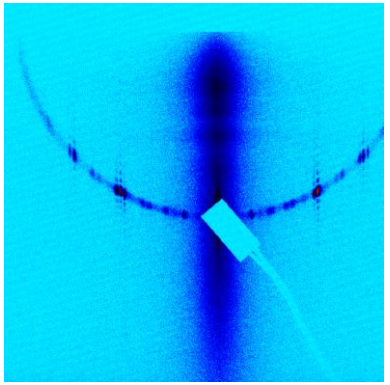
ON Resonance



OFF Resonance



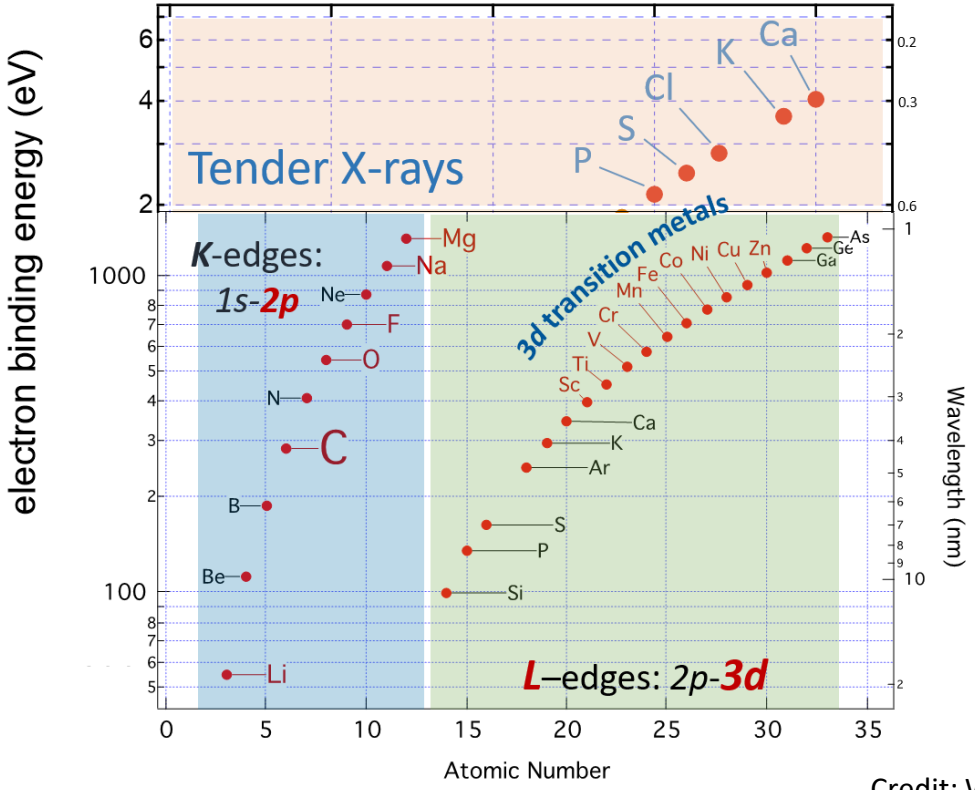
Resolving Printing Limit



Resonant Scattering Across Energies…

T-ReXS

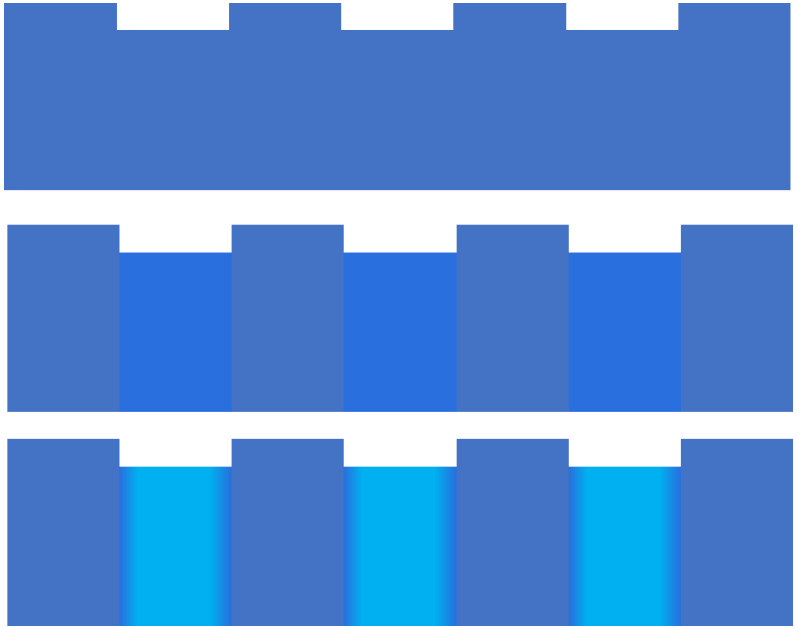
RSoXS



Credit: Wanli Yang & Greg Su

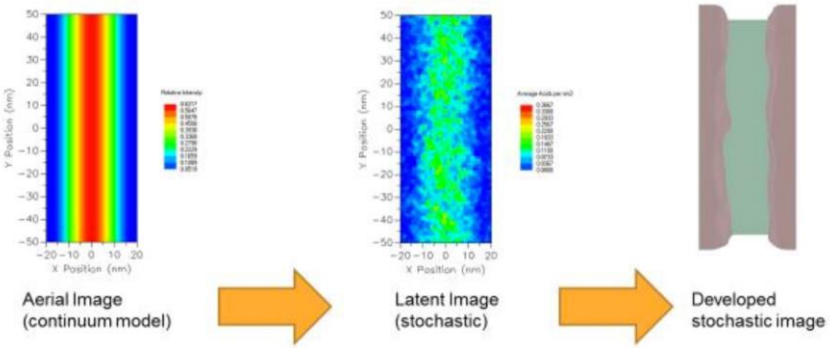
Exploring Impact of Different Resonant Edges

Chemical Profile at Carbon

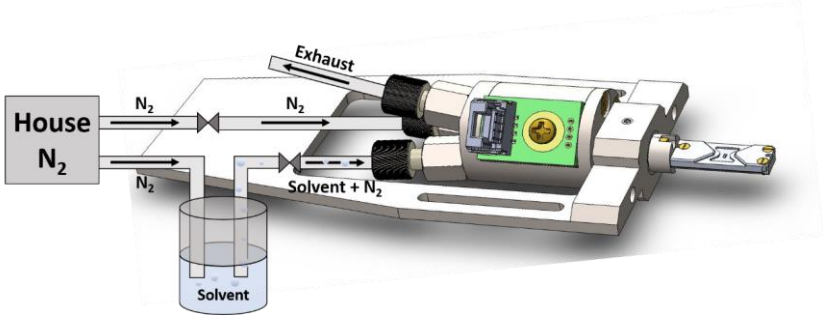


Chemical Profile at Oxygen

The Critical… Roughness Problem



Ref: http://semimd.com/blog/tag/euv/

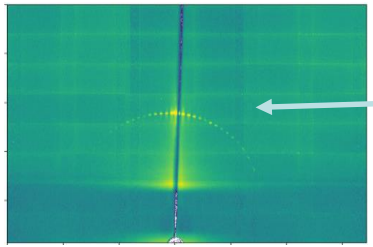


In-Situ Baking/Development/Post-Processing, etc

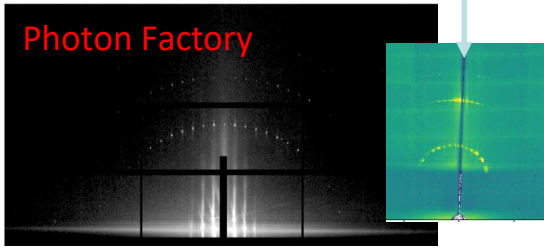
SEM Data

Tender-ReXS Data

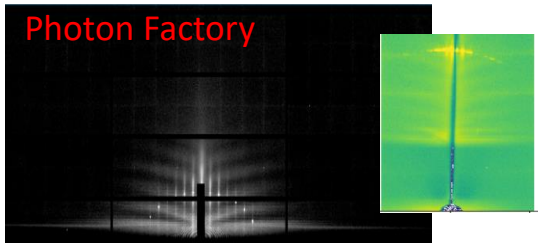
Low Roughness



Periodic Roughness



Aperiodic Roughness



Typical PEB times (~1 min)!

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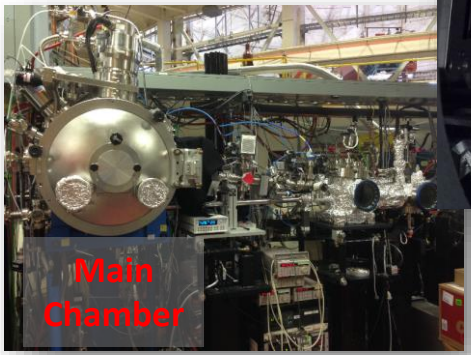
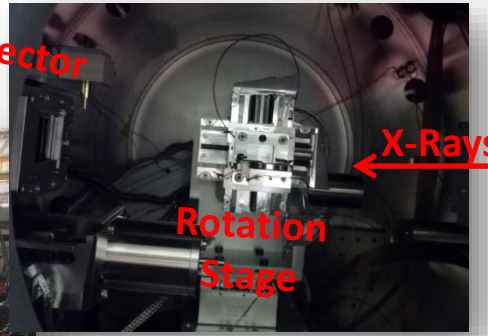
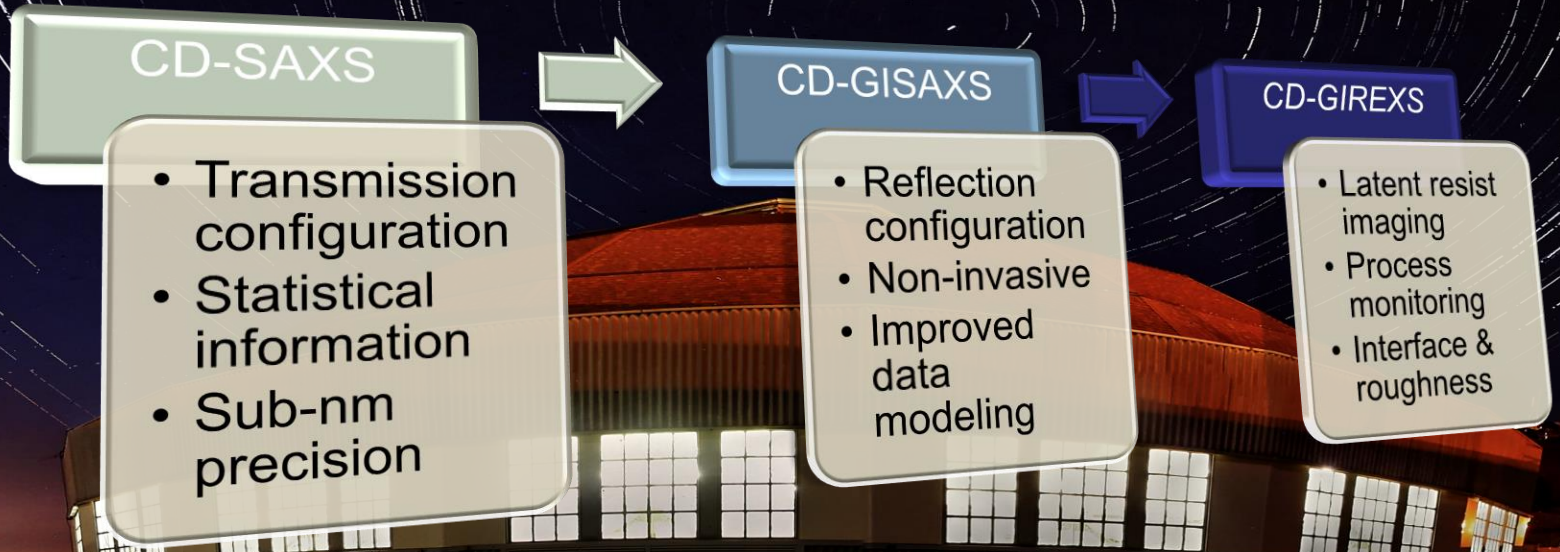




Beamline 11.0.1.2

***Key Contributors**

THANK YOU!



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