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

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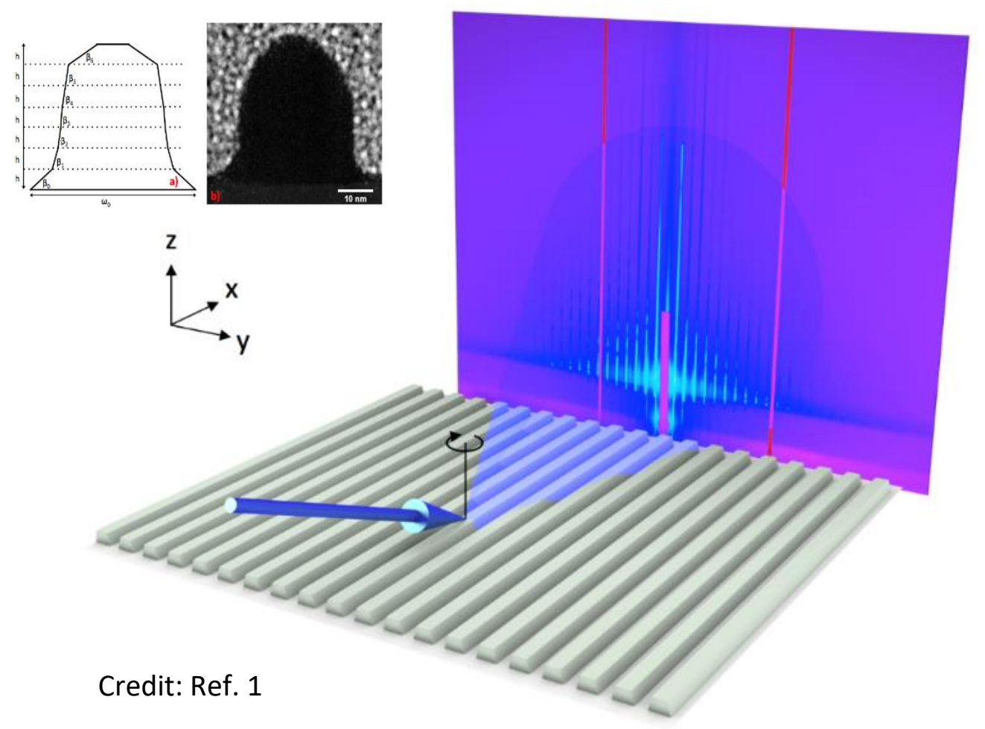
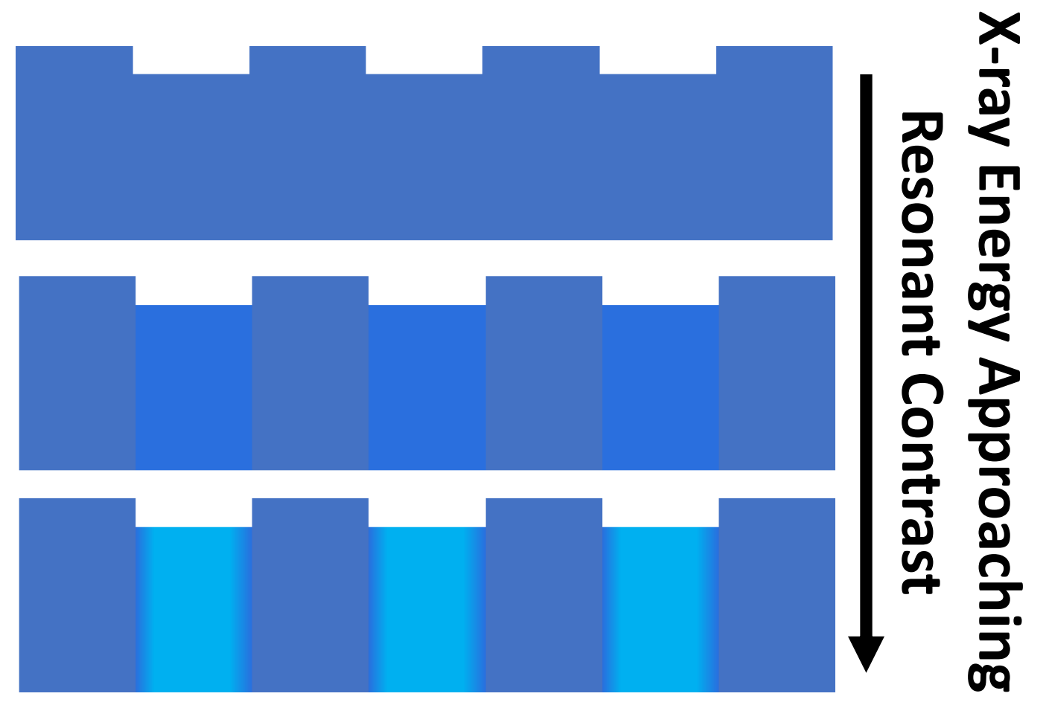
BACKGROUND

Introduction and Summary

We apply resonant elastic x-ray scattering (REXS) in a to extract the cross-sectional profile of patterned resists before they have been developed (i.e., latent image). We show how the difference in chemistry induced by the exposure and baking steps can produce enough scattering contrast at certain X-ray energies near a resonant absorption edge in order to provide a 3D latent image profile of the pattern with sub-nanometer resolution. In one case, we explain how latent images were acquired on PMMA and CAR resists by applying REXS near the Carbon K-edge. The reconstruction of this profile provides morphological information that can be compared with the final profiles obtained after development, but the REXS chemical contrast mechanism itself may also shed insight into the chemical nature of the exposure. We elaborate on the impact of the measurement itself (i.e. beam damage) on the resulting pattern morphology as well as how this approach may be applied across other types of resists. Altogether, this information can be used to shed light on the effect that various development and exposure conditions may have on the final resist features that are critical to modern lithography.

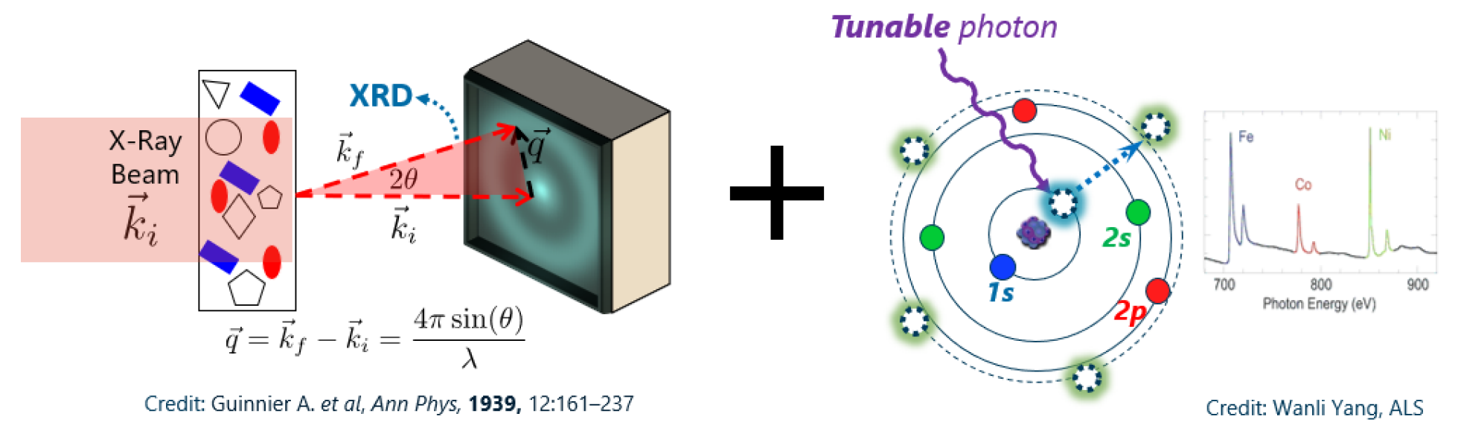


Credit: Ref. 1



Resonant X-Ray Scattering Fundamentals

Small Angle X-Ray Scattering **X-Ray Absorption (β)**



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

Credit: Guinnier A. *et al*, *Ann Phys*, **1939**, 12:161–237

Credit: Wanli Yang, ALS

Refractive Index $n(E) = 1 - \delta + i\beta$ ⇨ **Scattering Intensity** $I(q) \propto |\Delta n|^2 = |\Delta\delta^2 + \Delta\beta^2|E^4$

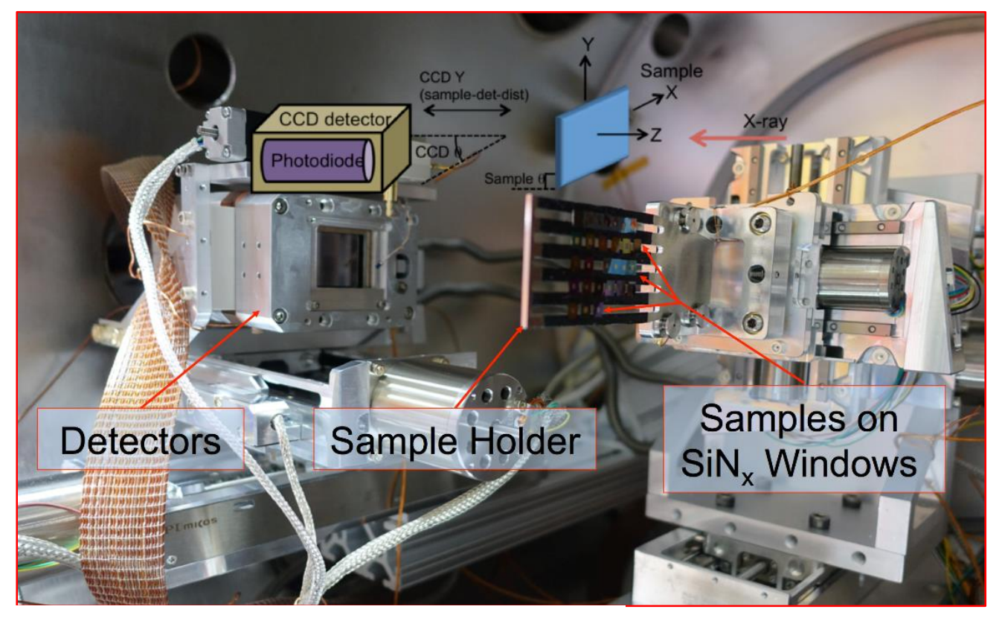
- Scattering contrast enhanced by tuning incident x-ray energy to a given element's absorption edge
- Enables chemically sensitive x-ray scattering techniques
- X-ray polarization control can provide molecular orientation.

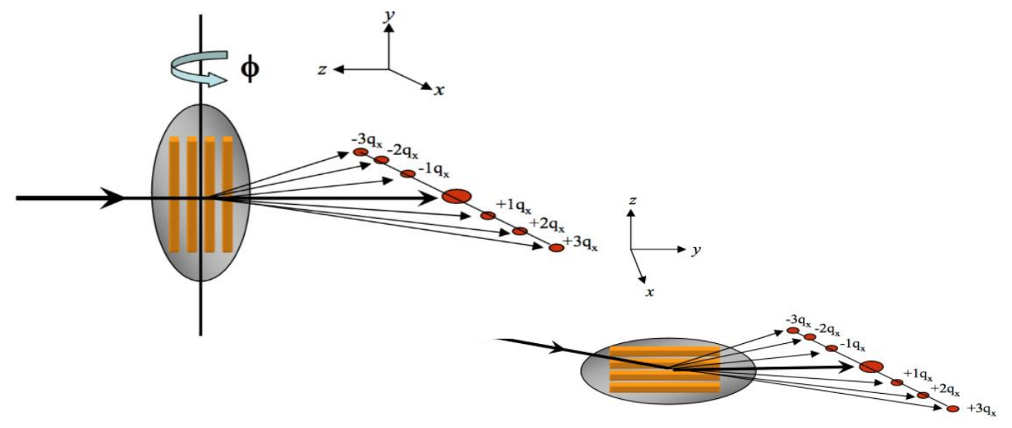
Combines dispersion, δ, with resonance absorption, β, to enable a chemically-sensitive morphological probe

ALS Resonant Soft X-Ray Scattering (RSoXS) Beamline

RSoXS Endstation Capabilities

- Spacious chamber (~1 m^3)
- Resolution E/ΔE ≤ 4000
- Full polarization control
- High vacuum compatible (~10^{-8} Torr)
- 1D detector (photodiode, CEM)
- 2D detector (PI-MTE In-Vacuum Camera, 2048 x 2048, 13 µm pixel)
- Motorized X, Y, Z motion for sample and CCD
- Sample-detector distance: 25 mm to 175 mm
- Sample exchange turnaround time < 1 hour
- 1000:1 suppression of higher order x-rays
- Three sets of slits for parasitic scattering
- Large q-range: 0.002-3 nm^{-1} at 280 eV; 0.006-10 nm^{-1} at 1000 eV
- XAS modes in Transmission (Bulk-sensitive), Total Electron Yield (1-20 nm probe depth), and Partial Fluorescence Yield (50-200 nm probe depth)



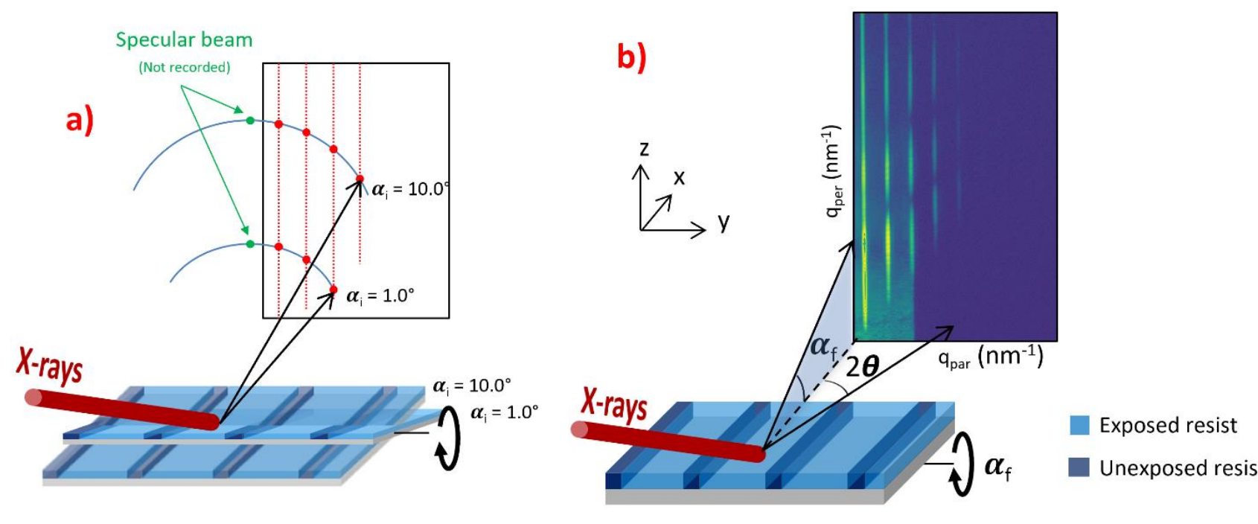


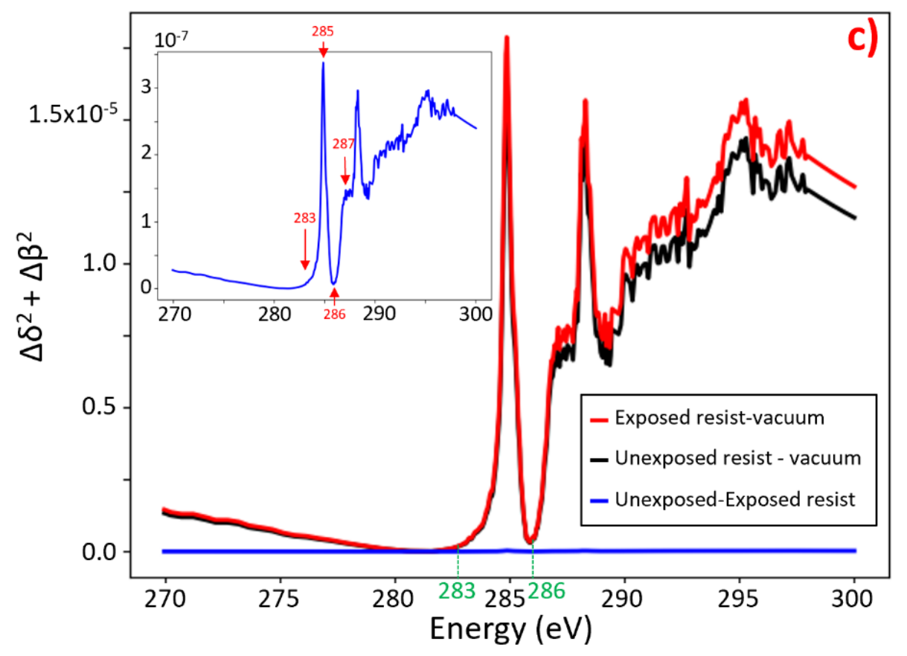
Rotation in Transmission and Reflection (GI) Configurations for **3-D Reconstructions**

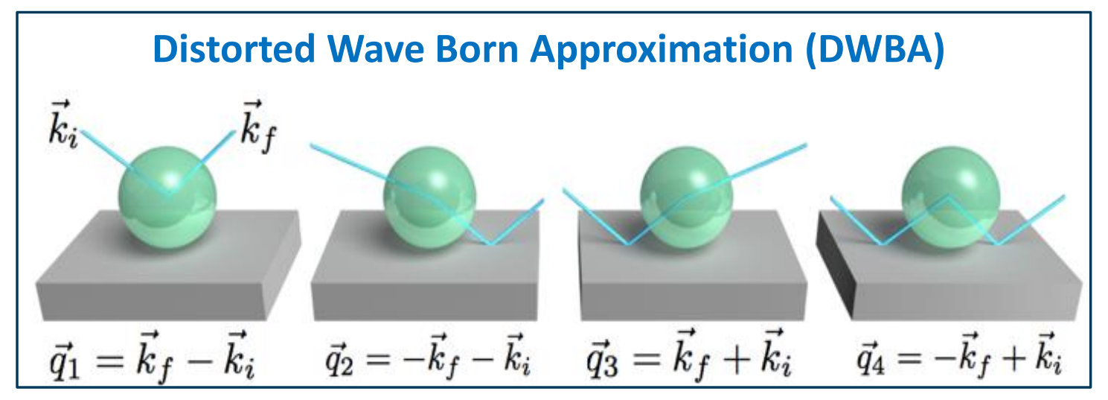
Soft X-ray Scattering Beamline Reaches 160-1300 eV

LATENT IMAGING OF EUV RESISTS

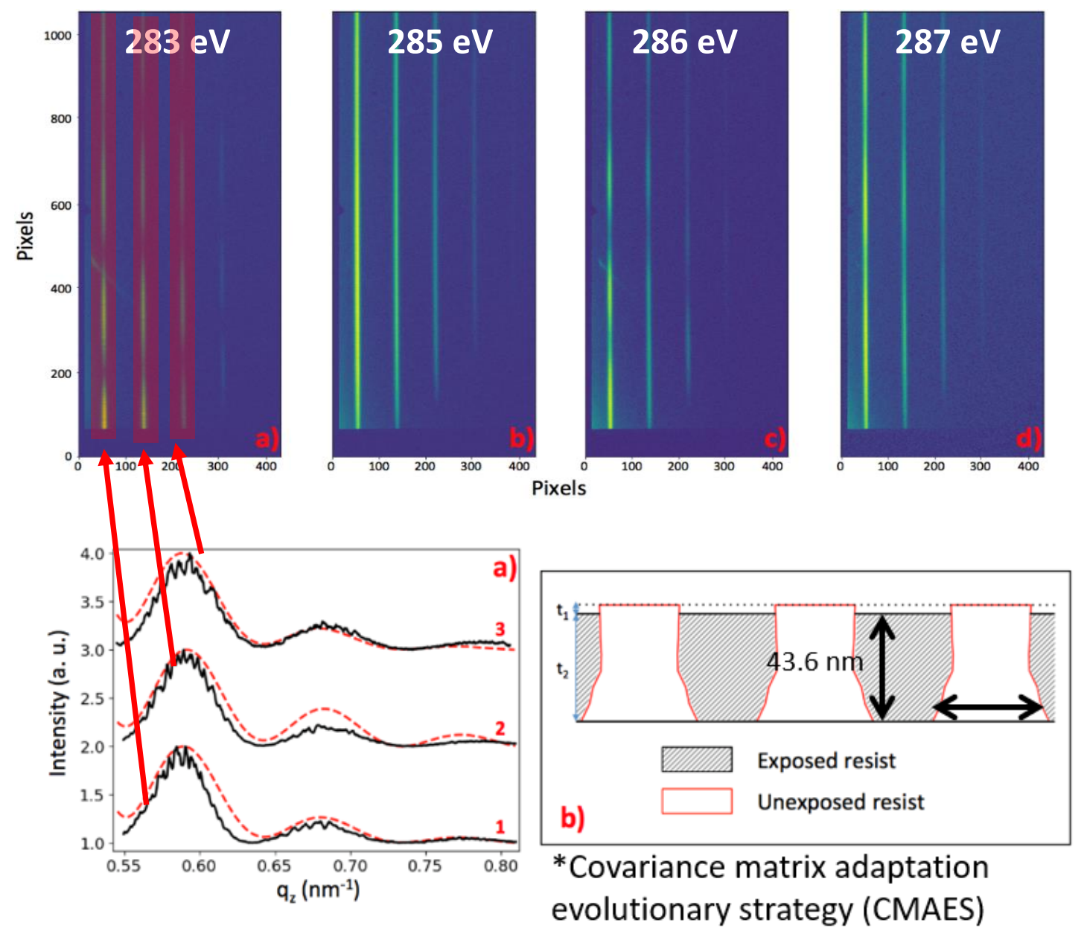
Grazing Incidence REXS for Latent Imaging of EUV Resist







- New analytical approaches **account for DWBA** enable **modeling of reflective scattering** data
- Reflection configuration enables **nondestructive** studies of resists on **native thick substrates**
- Scattering contrast due to **resonance is only** observed for **certain x-ray energies** near the carbon edge (i.e. ~ 283 eV & 286 eV)
- Resonant scattering scattering gives contrast due to **distribution of chemistry buried within resist**



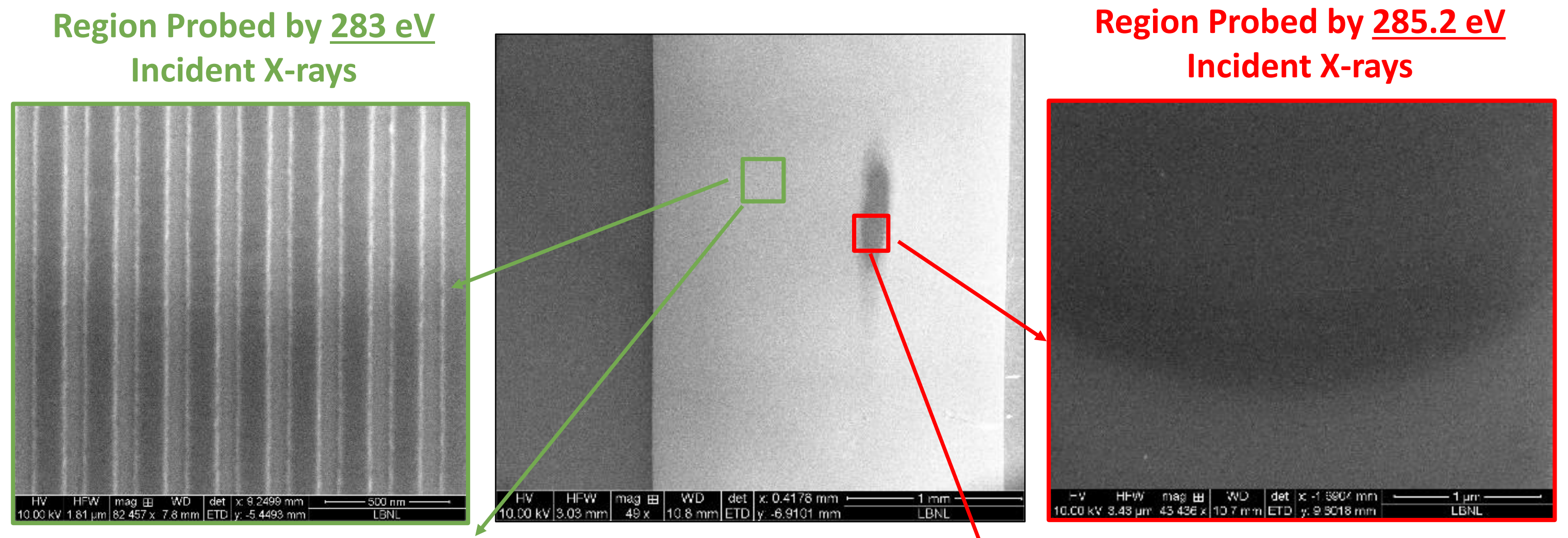
*Covariance matrix adaptation evolutionary strategy (CMAES)

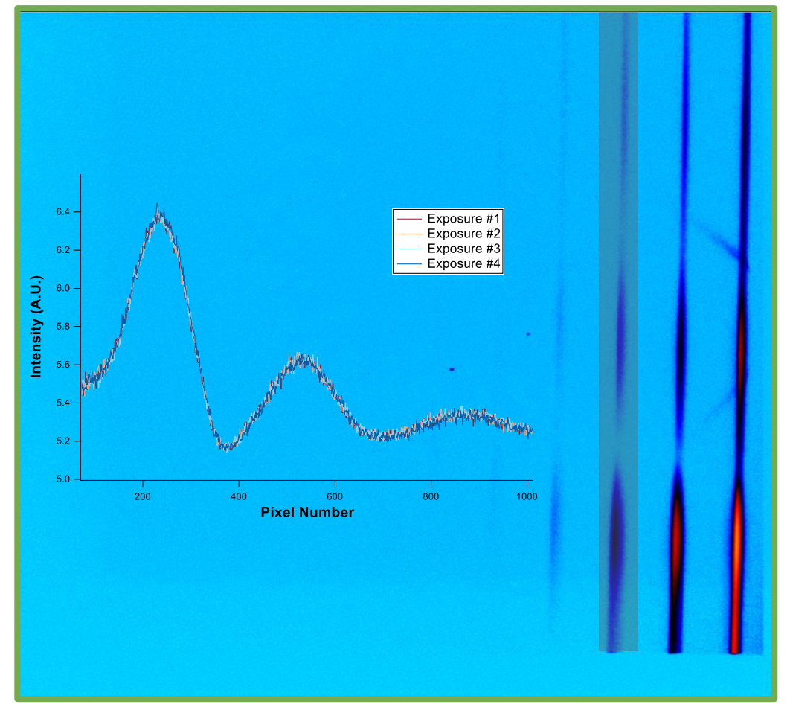
GIREXS Enables Extraction of Latent Chemical (Carbon) Profile from CAR Resists on Standard Silicon Substrates

Assessing the Impact of the GIREXS Measurement

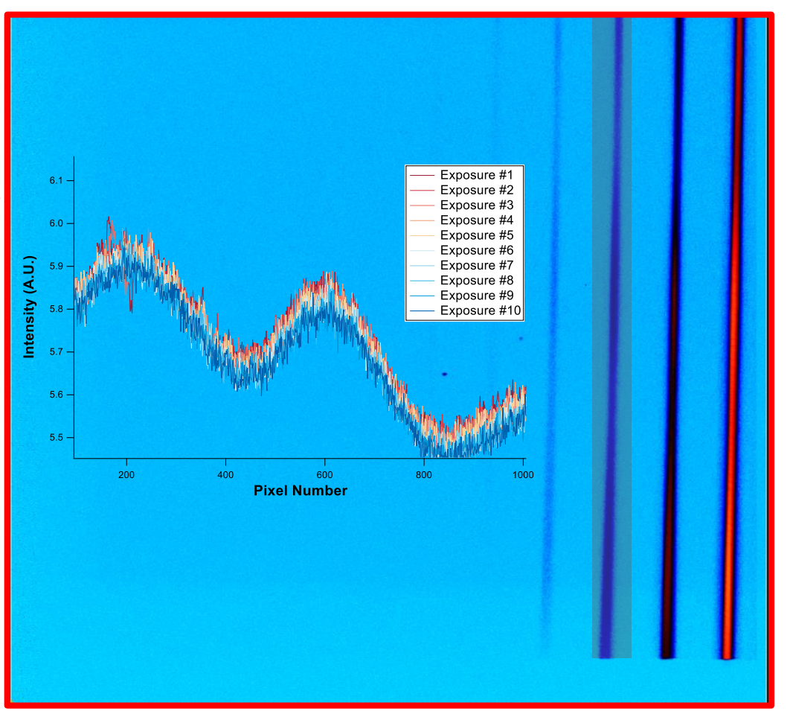
Region Probed by 283 eV Incident X-rays

Region Probed by 285.2 eV Incident X-rays





- **Regions probed with resonant** x-rays at 283 eV appear **unaffected**
- Scattering conducted with energies at **absorption peak** (not resonant) shows signs of **degradation**
- **Degradation mechanism** appears to be **chemical**, likely due to cross-linking

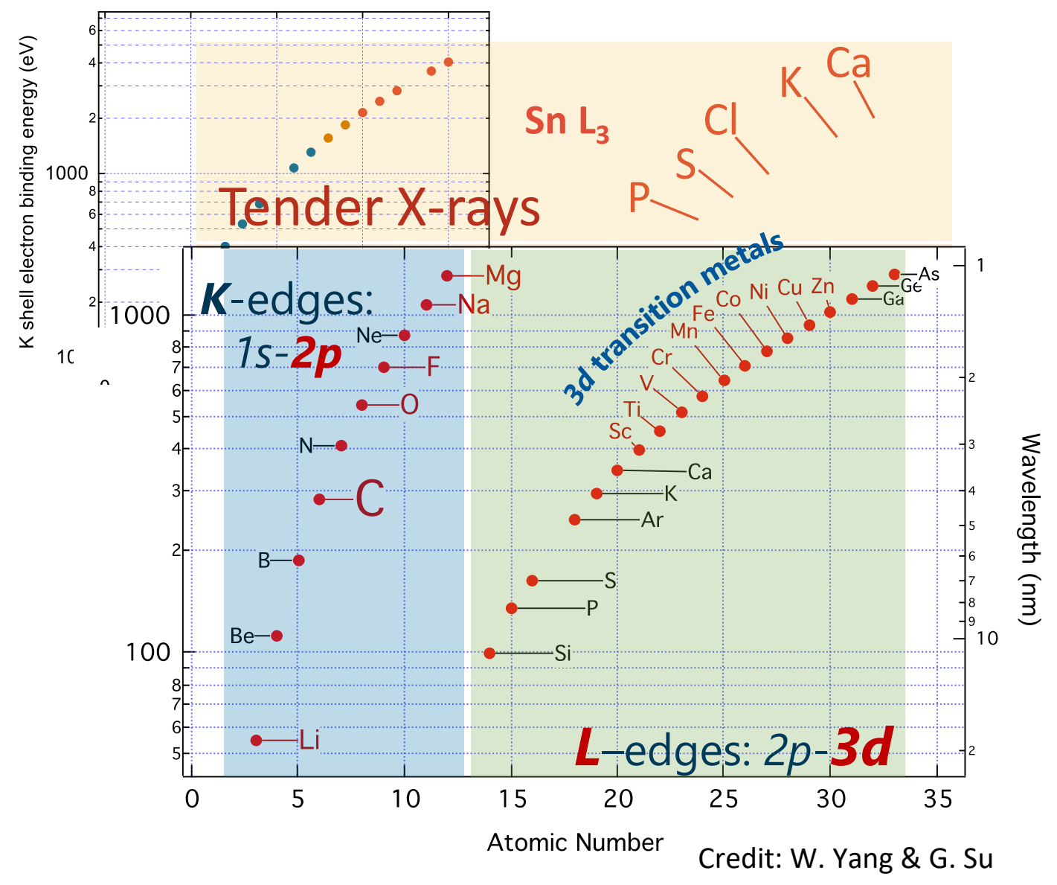


Impact on Final Developed Structure Appears Negligible at Energies Below Carbon Absorption Edge

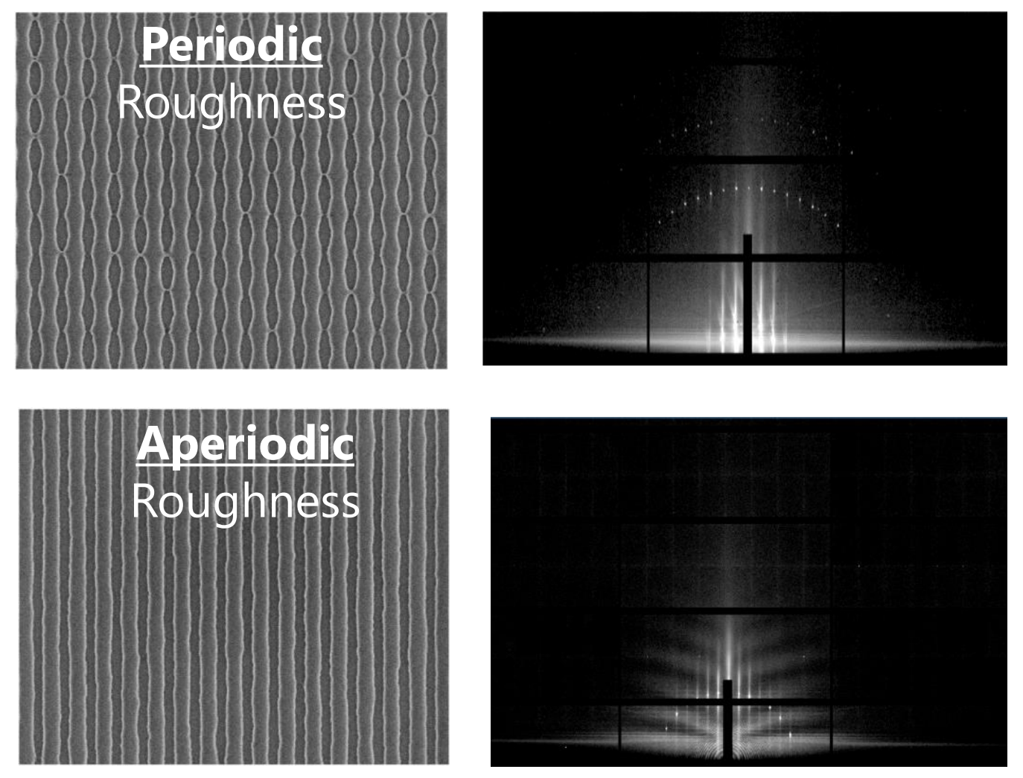
1. E. Gann and C. Wang et al, RSI, 045110, (**2012**)
2. G. Freychet and D. Kumar et al, Manuscript Submitted
3. G. Freychet & I. Cordova et al, J. Micro/Nanolith., 024003 (**2019**)
4. G. Su, I. Cordova, *et al*, *Polymer*, **2016**, 99, 782

OPPORTUNITIES IN EUV LITHO

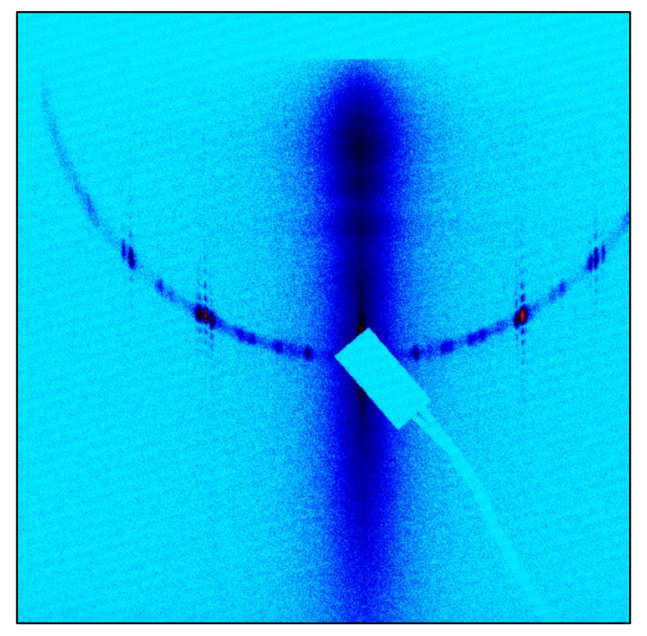
Interrogating Interface Roughness and Local Chemistry



Credit: W. Yang & G. Su

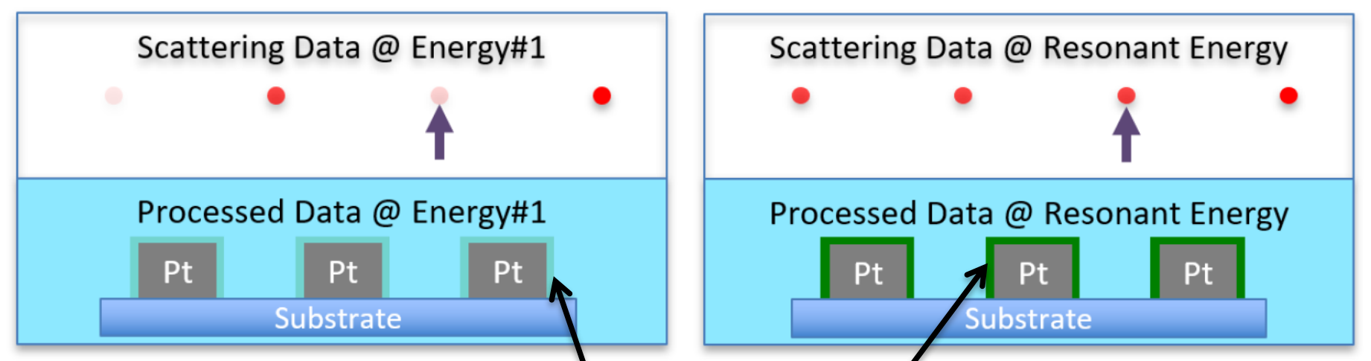


Other X-ray Energies** (e.g. Tender on the right) **Captures New Physical Features with Sensitivity to Higher Z Chemistries



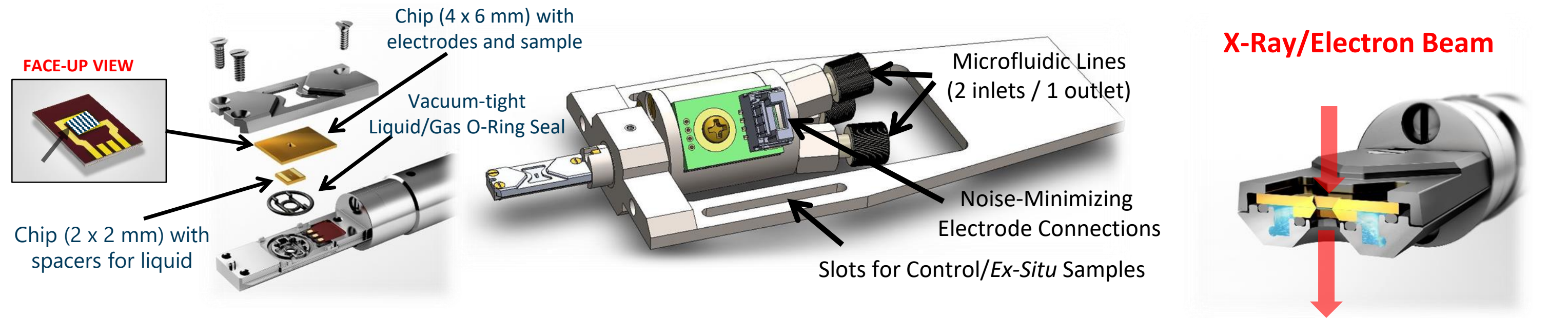
***Undeveloped PMMA Resist at Oxygen Edge with 20 nm Pitch** (below lithographic limit)*

***Combining Designed Patterning and Resonant Scattering can Selectively Probe Buried Interfaces** (e.g. Underlayer)*

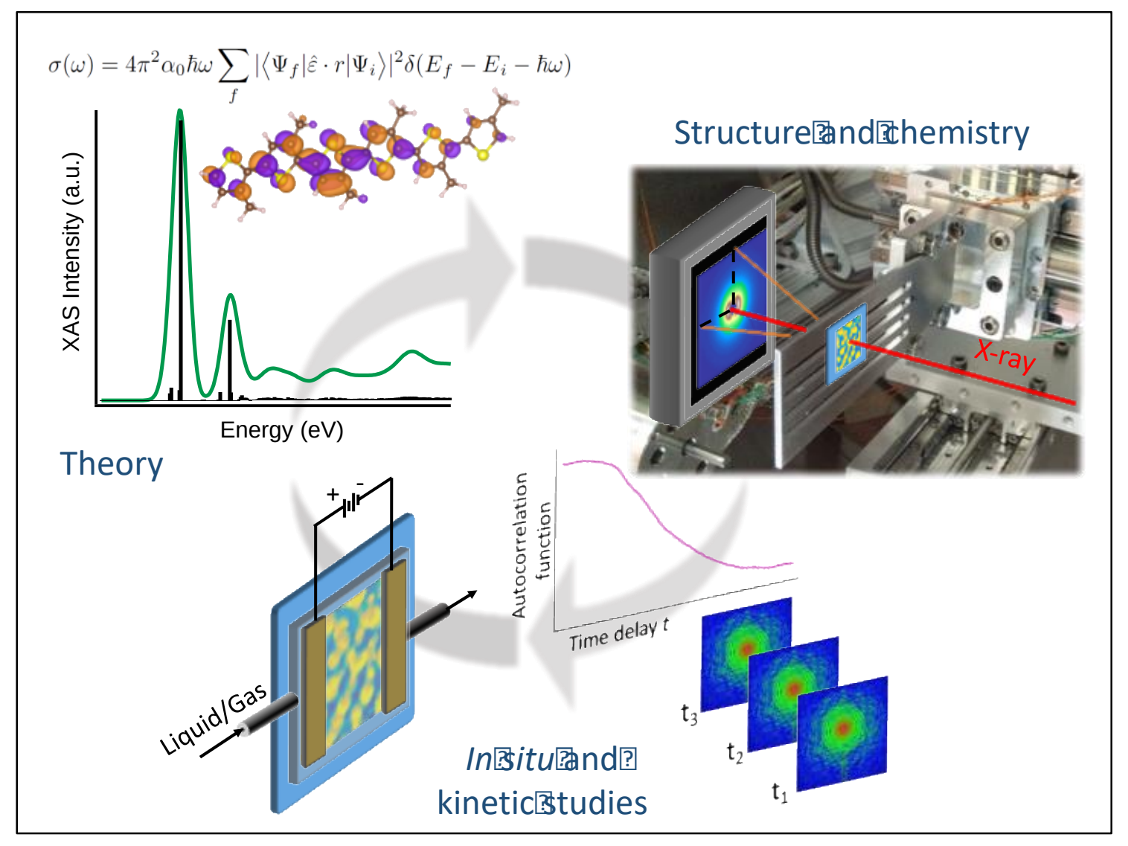


Resist/Underlayer Interface

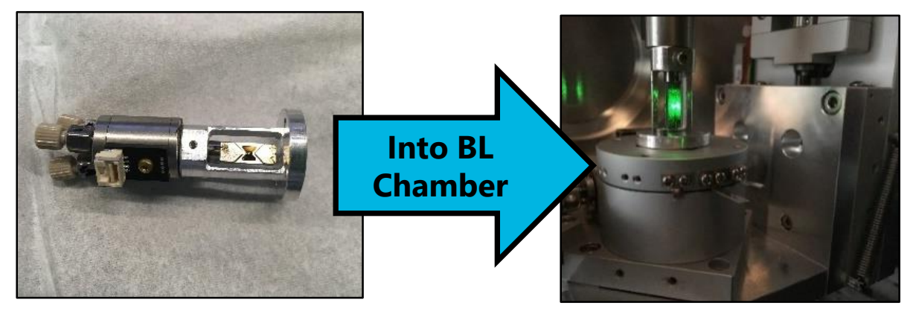
Vision for Future of *In-Situ* REXS



Credit: Images of Poseidon Select™ system provided by Protochips Inc©



Credit: Ref. 4



- **Homemade *in-situ flow* cell** shown above enables characterization of samples under **real atmospheric conditions** (e.g., controlled humidity, solvents, developer, heating)
- **Versatility of design** enables complementary testing of same samples with other tools (e.g., RSoXS, T-REXS, STXM, TEM, etc)
- Combining *in-situ* techniques with novel coherent sources, detectors, and chemical theory will enable deeper understanding

Combining REXS approaches with Local Expertise and Capabilities Will Enable New Opportunities for Probing Dynamics and Kinetics of Novel Resist Processes