Production-Ready Hybrid Metrology for Deep 3D Structure Profiling Using SE and X-ray Diffraction

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6” 8” 12”

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Agenda

1. Limitations of Optical SE in Deep 3D Structures
2. Advantages of X-ray Diffraction Metrology
3. XCD Measurement Performance
4. Performance Enhancement Using MGML

Limitations of Optical SE for Deep 3D Structure Monitoring

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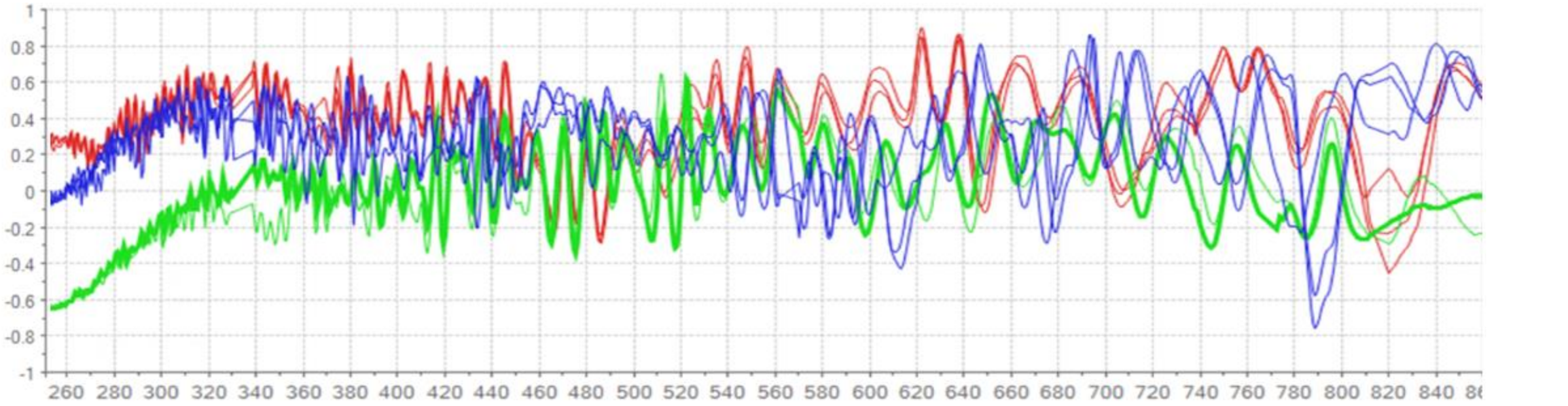
Deep VNAND structures generate strong spectral ripple and weak metal sensitivity, which reduces structural resolution in SE-based metrology.



Adoption of XCD for Deep Structure Monitoring

X-ray diffraction directly captures periodic structural variations and provides stronger sensitivity for deep 3D structures than optical methods.

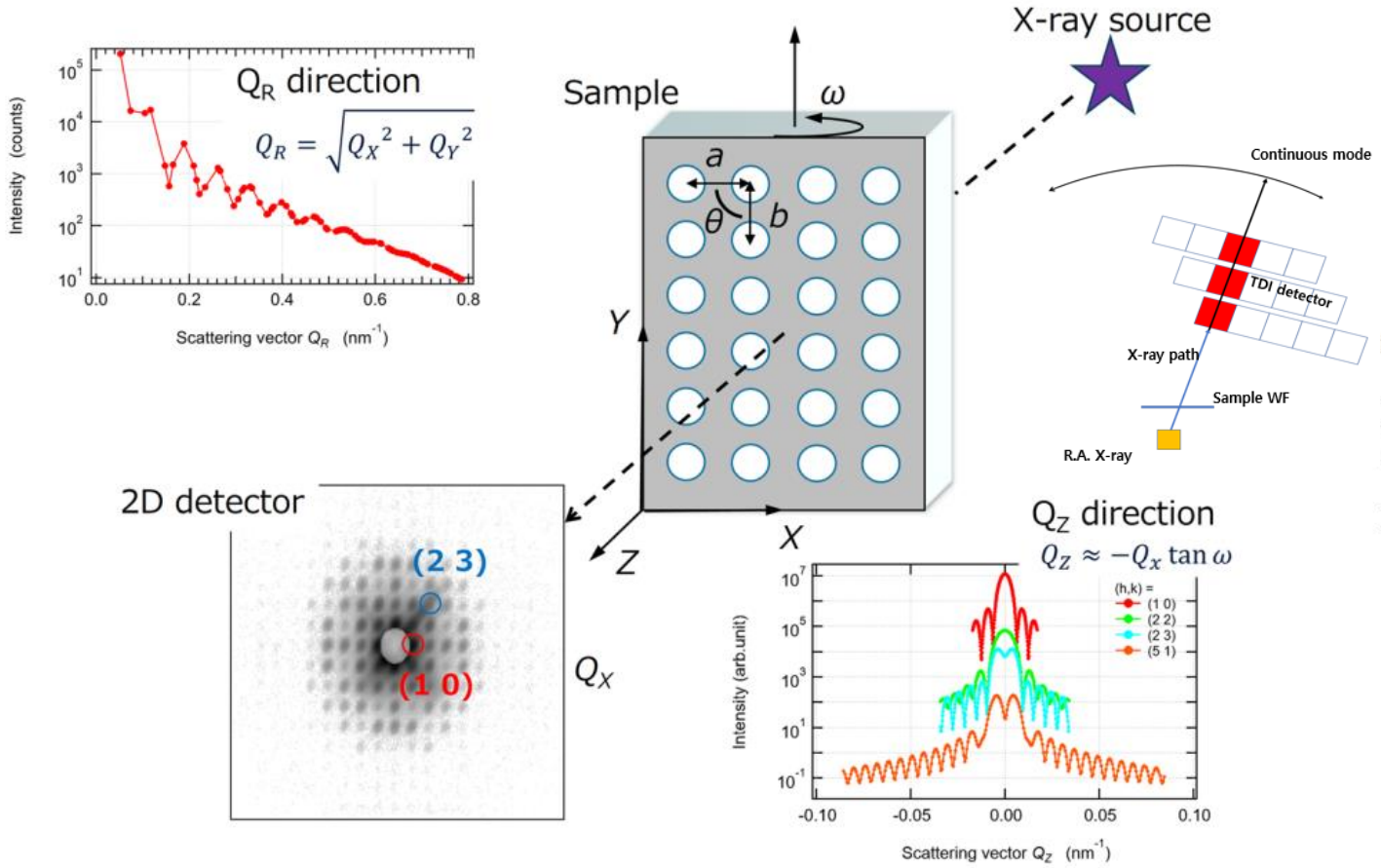
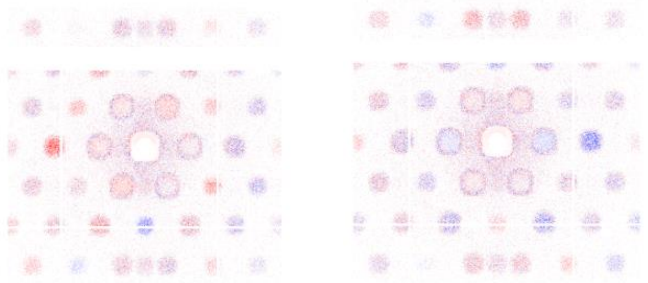


Fig. 1. Measurement geometry for transmission small-angle X-ray scattering.

CD Difference from XCD Diffraction Residuals



CD 19-18nm CD 20-19nm

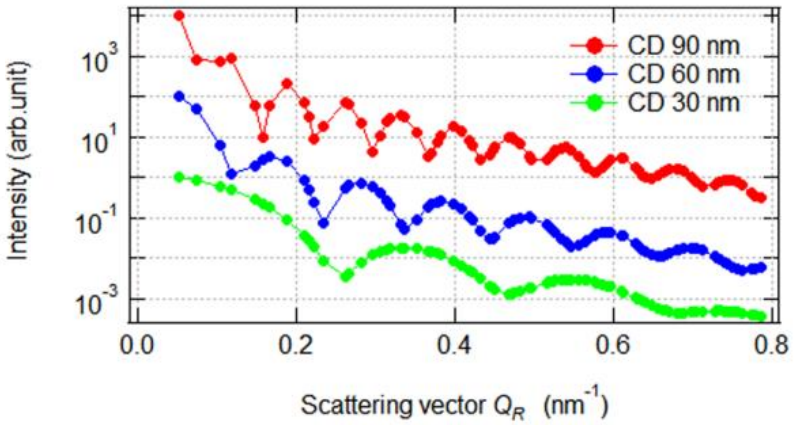


Fig. 3. Calculated intensities in the Q_R direction of a cylindrical hole with different CDs.

* Some materials provided by Rigaku

Direct Structural Sensitivity of X-ray Diffraction

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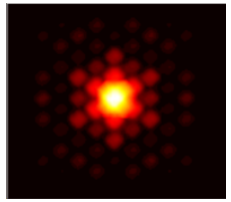
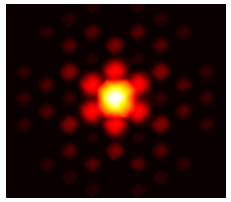
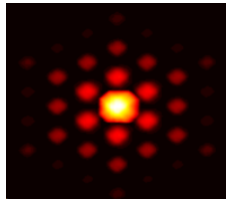
Changes in pitch and layer thickness produce clear shifts in diffraction patterns, enabling sensitive structural monitoring.



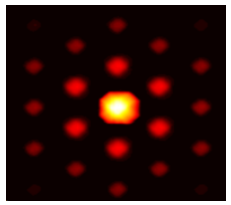
Pitch=120nm



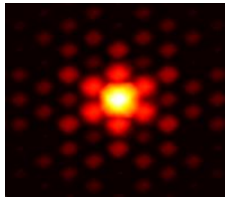
Pitch=95nm



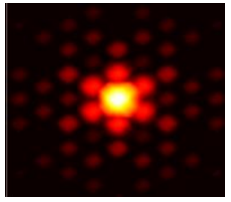
Pitch=70nm



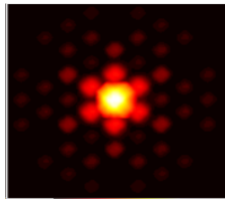
Pitch=50nm



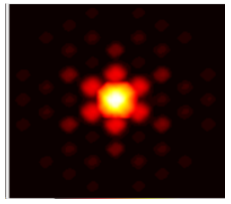
Height=1.4mm



Height=1.2mm

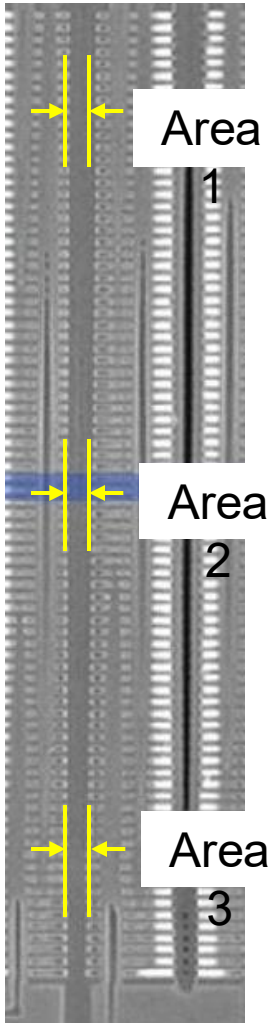


Height=1.0mm

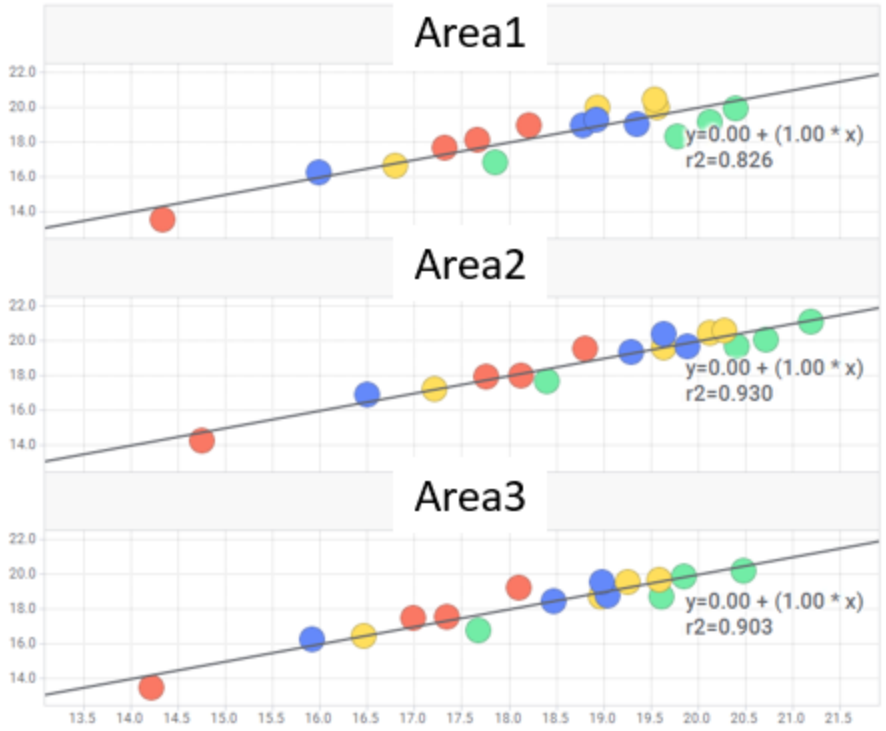


Height=0.8mm

XCD Demonstrates Production-Level Measurement Capability



Measurement time was reduced from 30 minutes to about 5.7 minute while maintaining correlation with reference data.



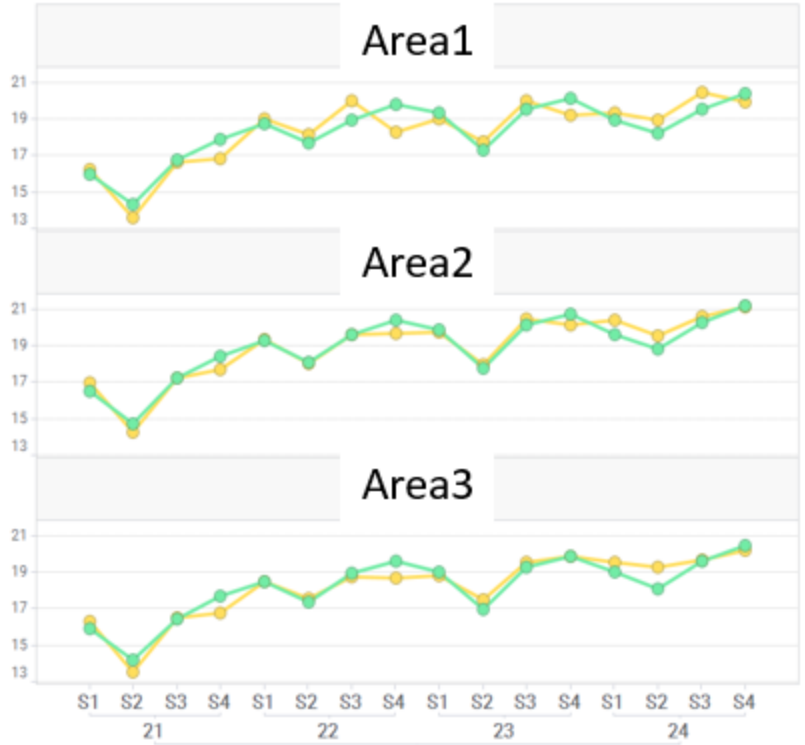


Image from :
https://www.techinsights.com/blog/techinsights-memory-technology-update-iedm18

Remaining Challenges in Production XCD Metrology

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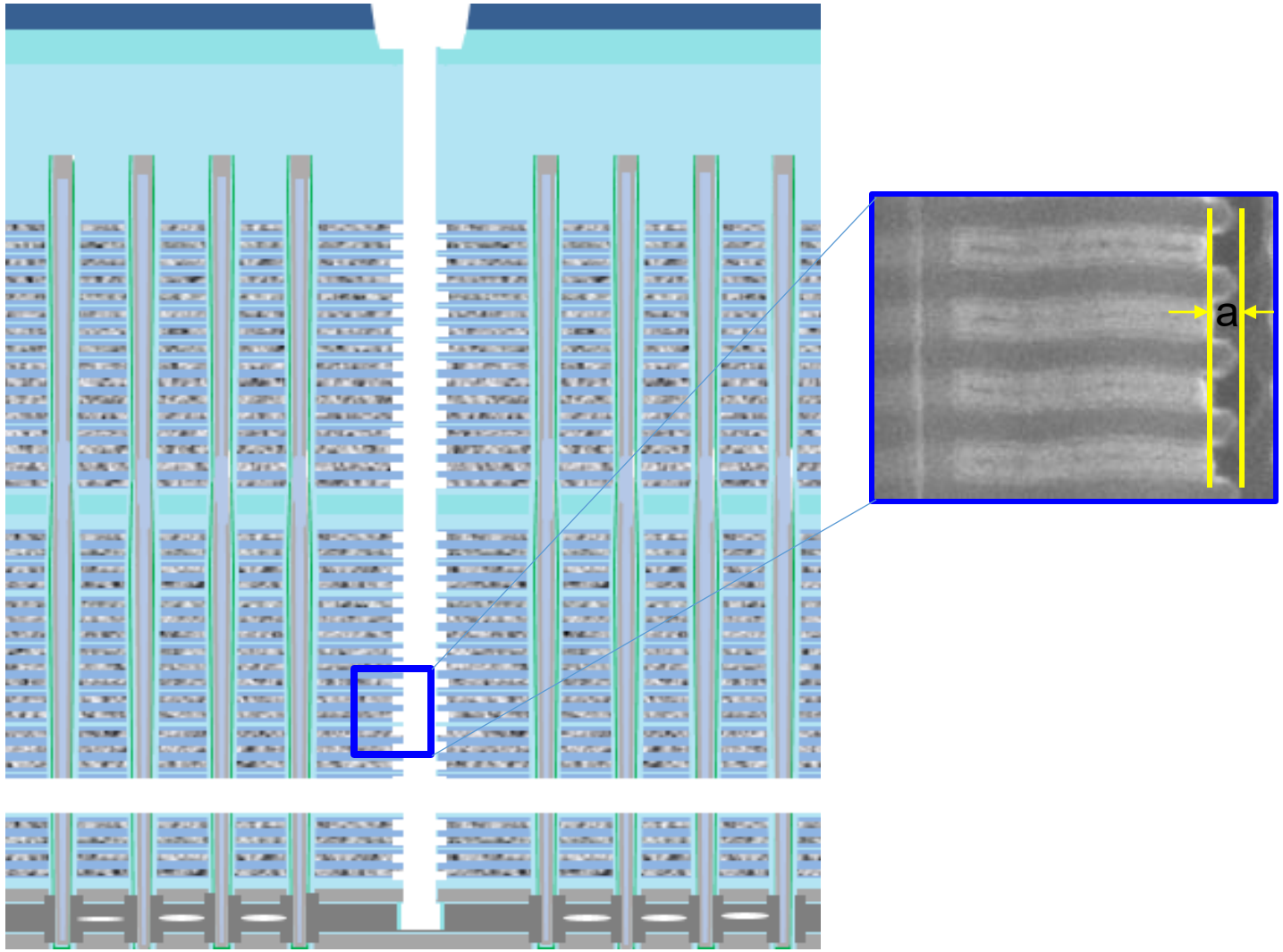
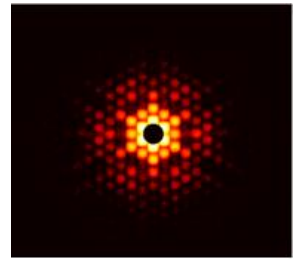
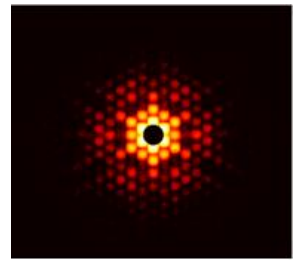


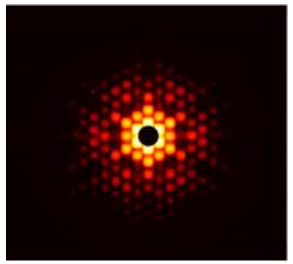
-3nm



0nm



+3nm



R2= 0.6 @12min

R2= 0.6 @6min

Overview of Model-Guided ML(MGML) Framework

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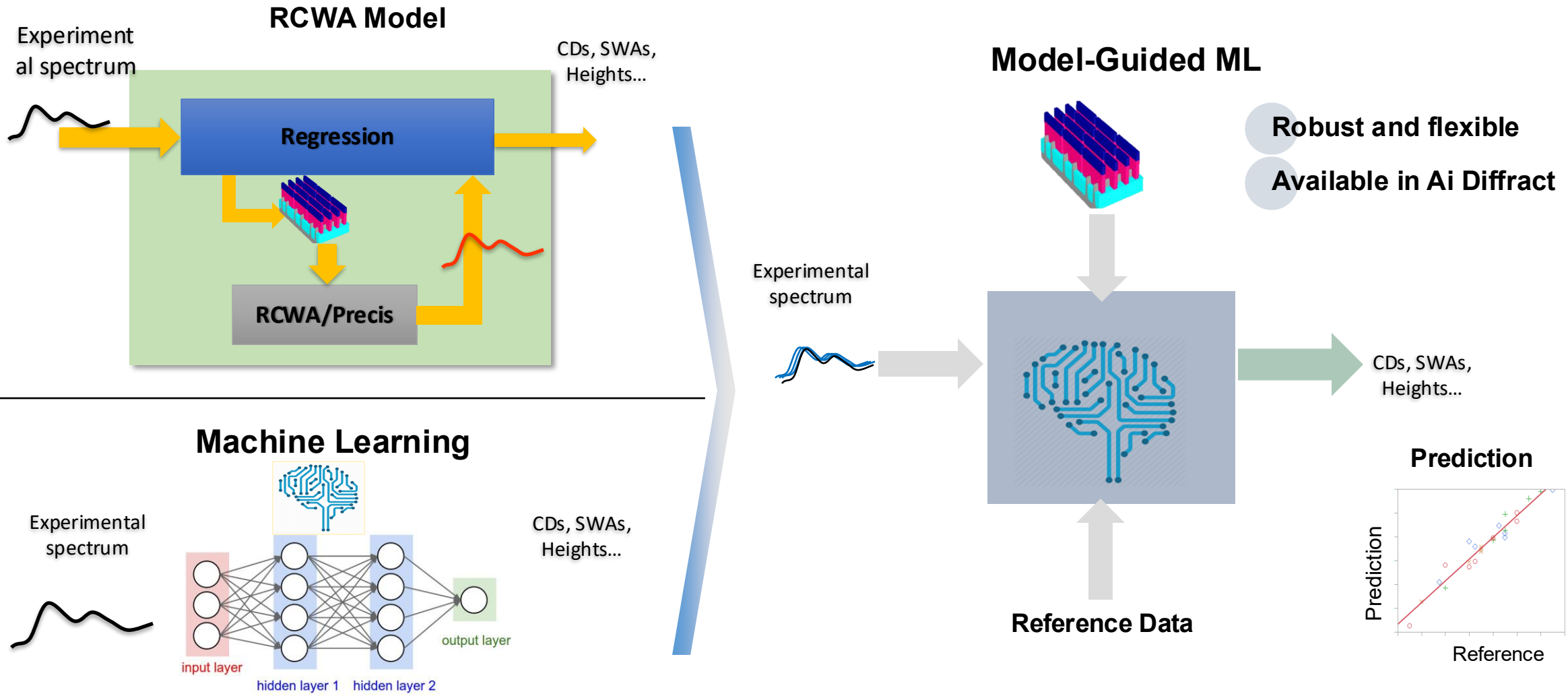
- Enables critical layers with great performance and time to solution



* Some materials provided by Onto

MGML Performance Improvement in OCD

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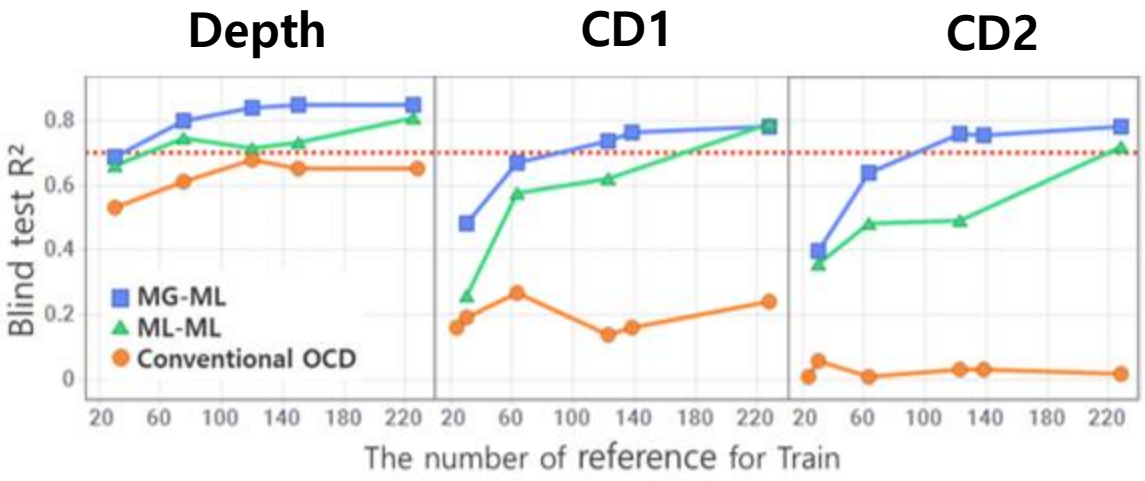
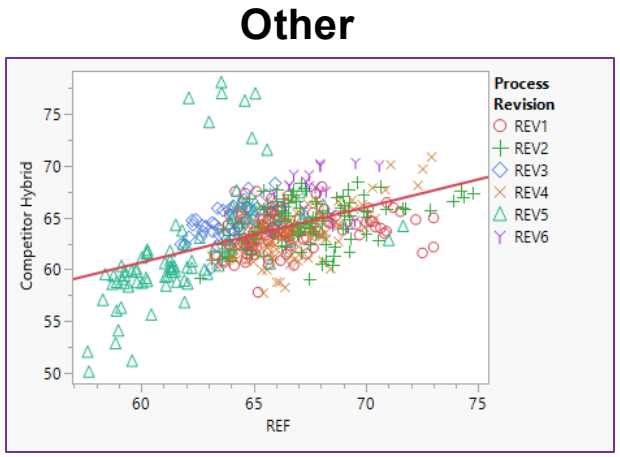
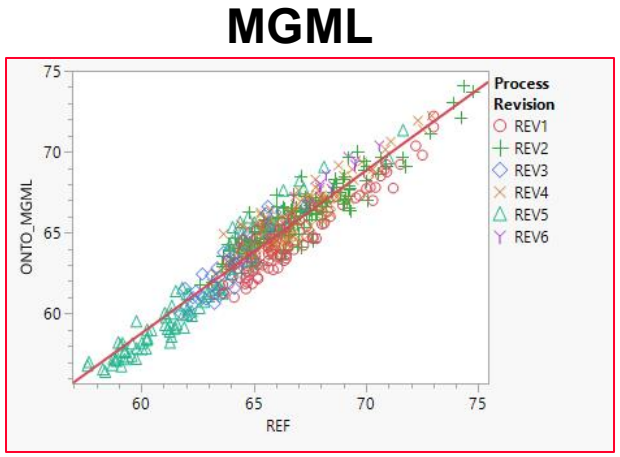
Achieving Satisfactory R^2 with Limited Sample Size



Reduced Recipe Model Revisions Under Structural Changes





* Some materials provided by Onto

MGML Improves Correlation Across Items

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Correlation by Item

	2F TOP	2F BTM	1F TOP	1F BTM
Tool Model	0.63	0.72	0.65	0.67
/w MGML	0.72	0.82	0.78	0.81

CD SAXS Measurement

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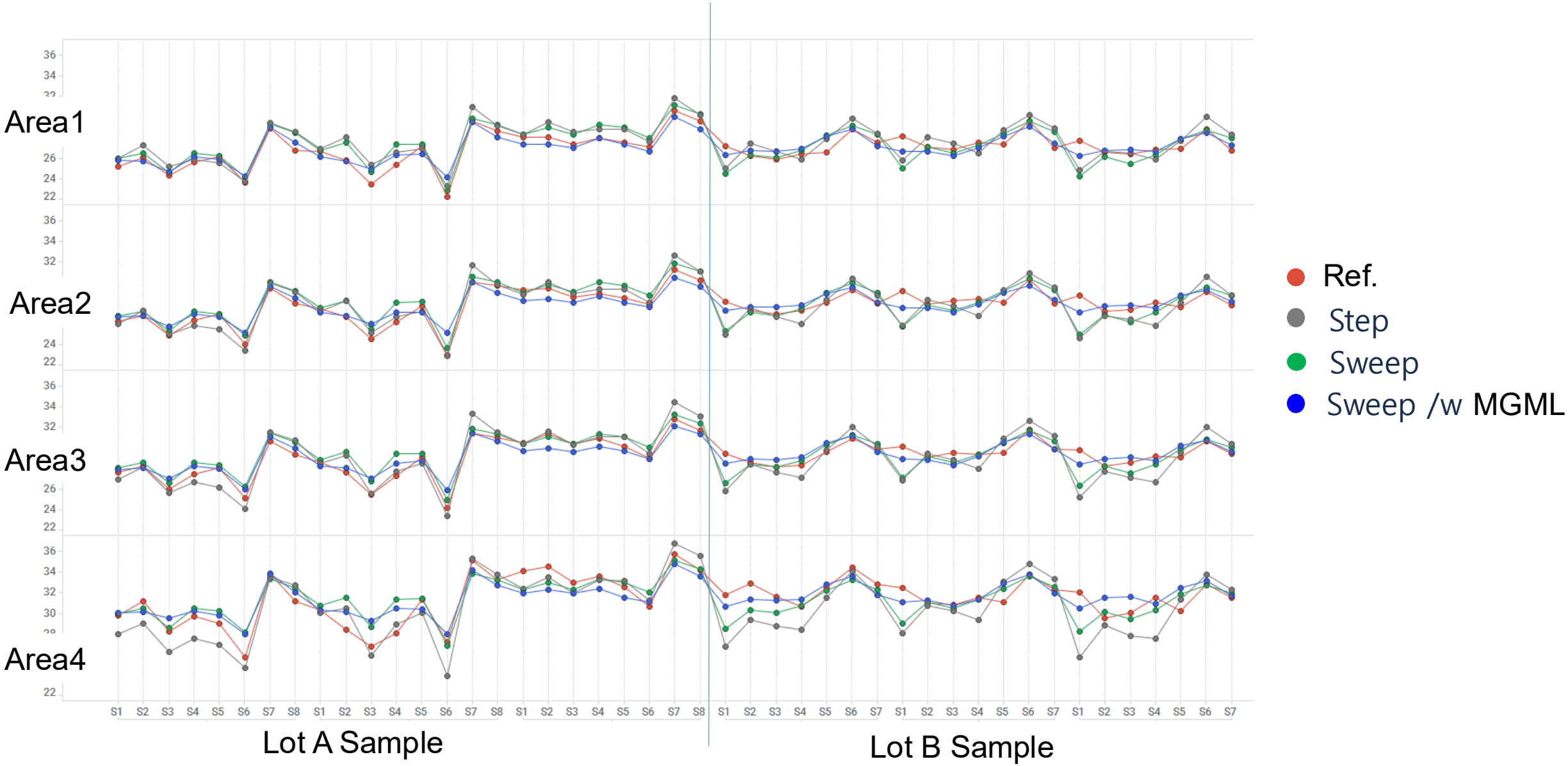

Diffraction Signal Amplitude Differences

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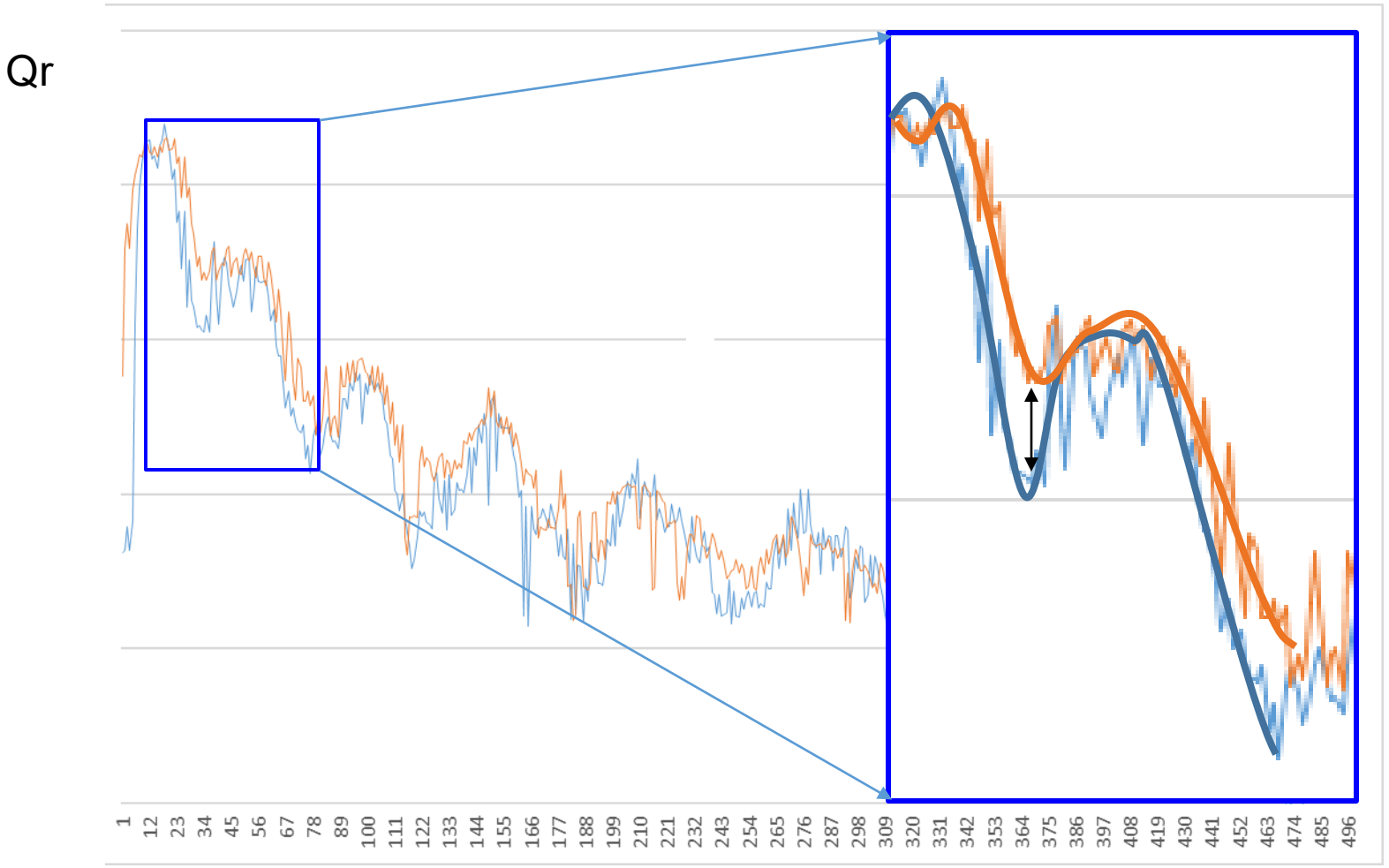

- Good Correlation
- Bad Correlation

Noise Dominance Causes Modeling Instability

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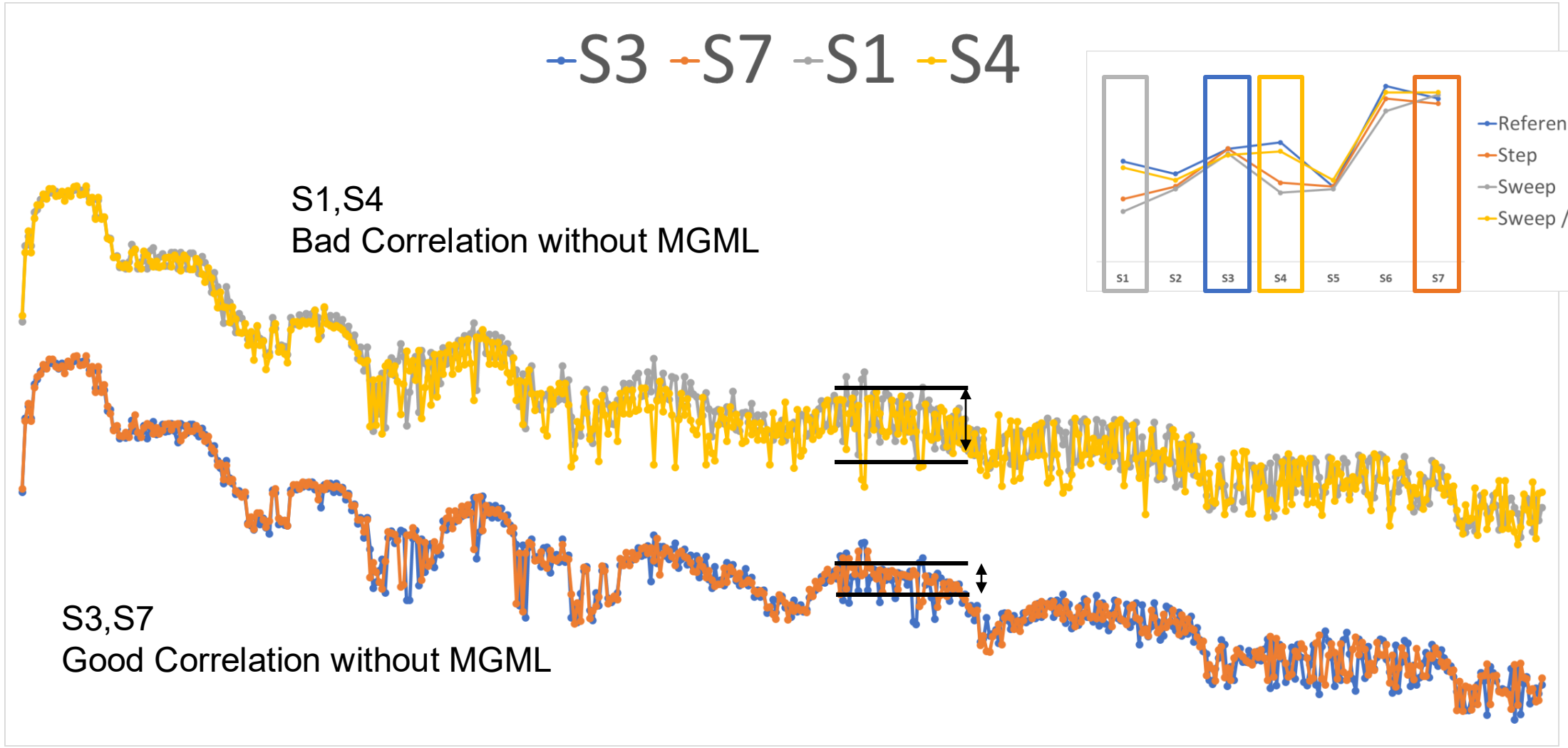
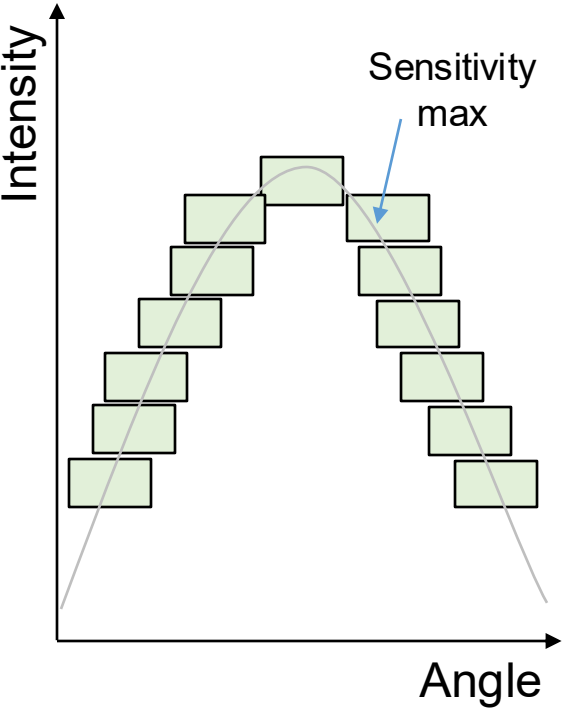
MGML helps separate structural signals from random noise, improving modeling robustness.



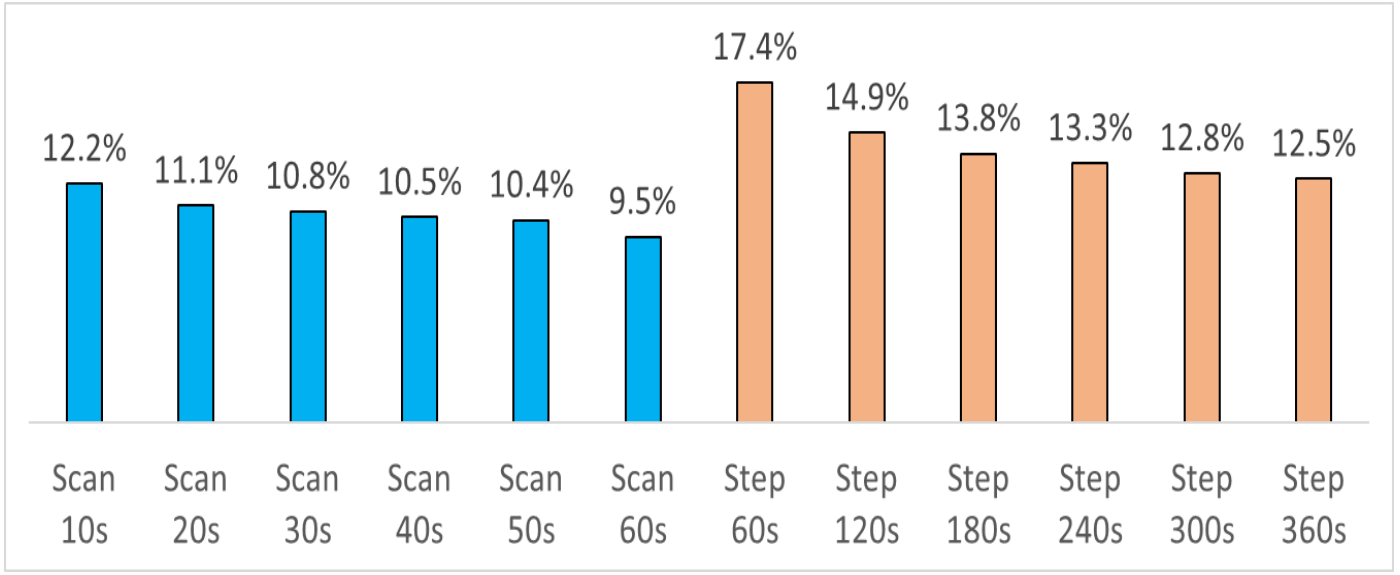
Discussion1. Continuous Scan and Step Scan

The reproducible noise characteristics of continuous-scan diffraction signals enable MGML to achieve reliable structural matching even with shorter scan times.

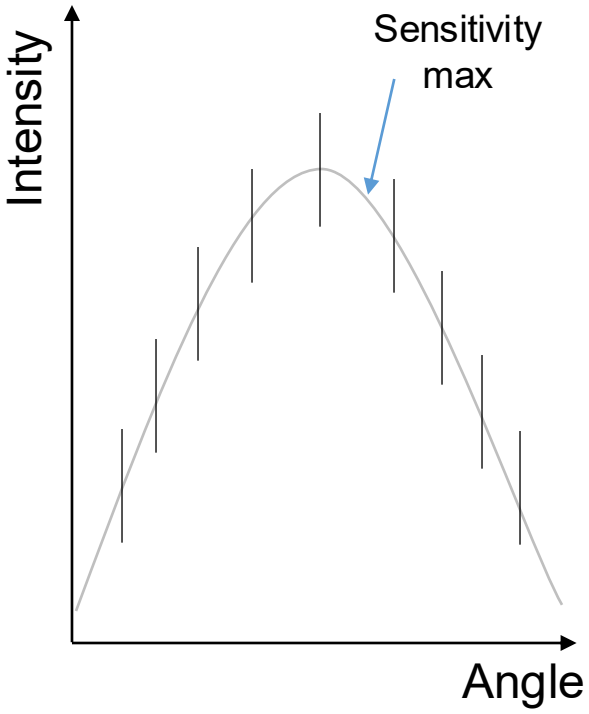
Sweep Mode



Qz Signal Stability (MSE) (n = 5 static measurements)

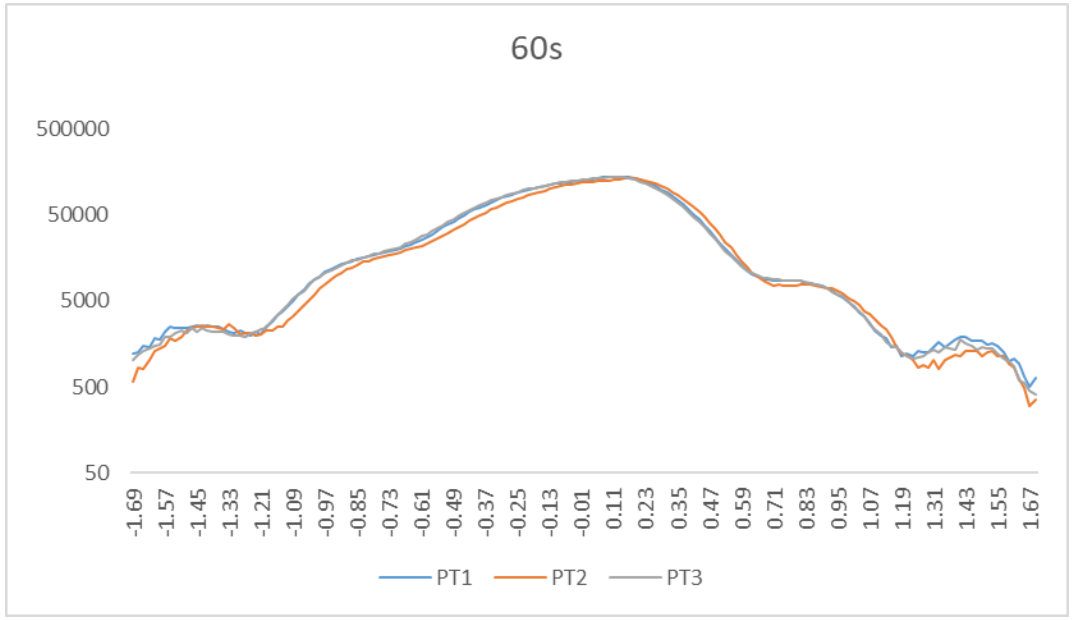


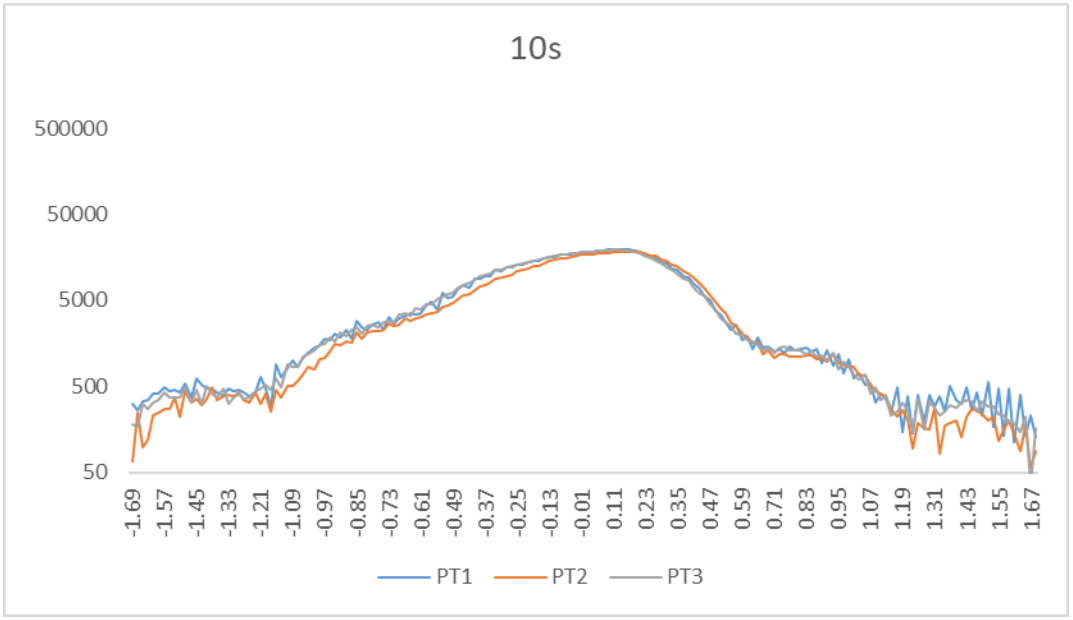
Step Mode



Discussion 2. Sensitivity and Noise

The structural diffraction features remain separable even under noisy short-scan conditions, enabling MGML to recover CD information.





PT1 : 32nm
PT2 : 33nm
PT3 : 34nm

Conclusions and Future Work

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Summary

- X-ray diffraction enables structural monitoring beyond optical SE for deep VNAND.
- MGML improves agreement with reference measurements toward production targets.
- Continuous scanning stabilizes signals and supports shorter, production-ready recipes.

Future Work

- Further reduce scan time while maintaining robustness.
- Extend the approach to more complex 3D architectures.
- Integrate more advanced model-guided analysis.

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THANK YOU

For inquiries regarding this work, please contact:
ys0602.kim@samsung.com