Advanced FTIR Optical Modeling for Hydrogen Content Measurements in 3D NAND Cell Nitride and Amorphous Carbon Hard Mask

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Overview

- FTIR Systems Improvement and Advanced Modeling Capabilities Enable **Low Hydrogen Content** Measurements
- Use Case A: Measuring H% in NAND Cell Nitride Two Test Wafers with Different Processes
- Use Case B: Measuring H% in Opaque Amorphous Carbon Hard Masks in Three Process Control Wafers with DOE Skew
- Scientific Conclusions and Summary of the Tool Improvements

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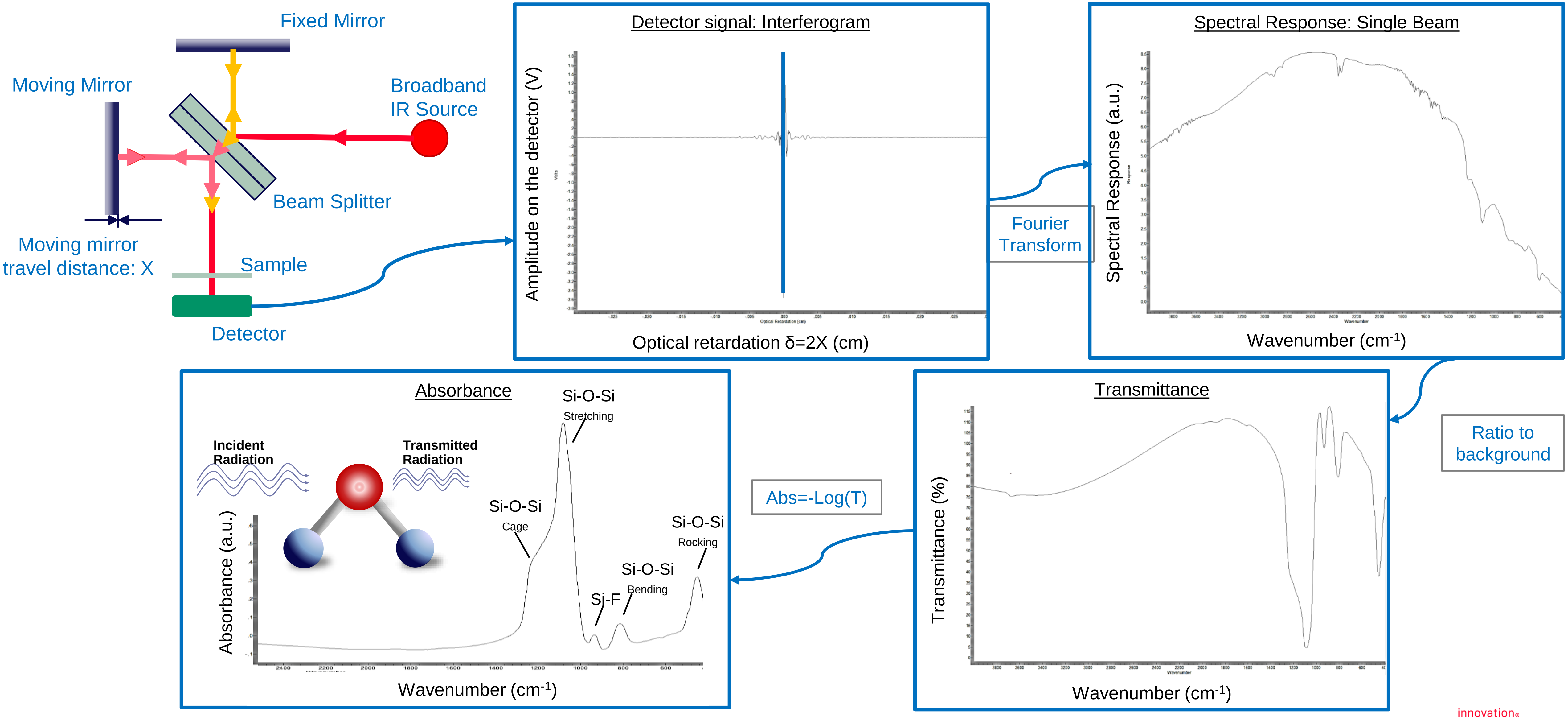
How FTIR System is Used to Measure Chemical Composition



ONTO Next Gen FTIR system with Improved SNR

Enabling measurement capability on **low sensitivity** parameters, including Small H% Characterization

7X Better SNR @ 2mm IR Spot than previous generation

- New IR source with 75% higher energy
- Newly designed high reflectivity IR optics
- New KBr window with 2x better transmission
- High D* with optimized detector size & response

ONTO Advanced IR Modeling Algorithm

Use Case A: H% in Silicon Nitride Test Wafers with Two Processes

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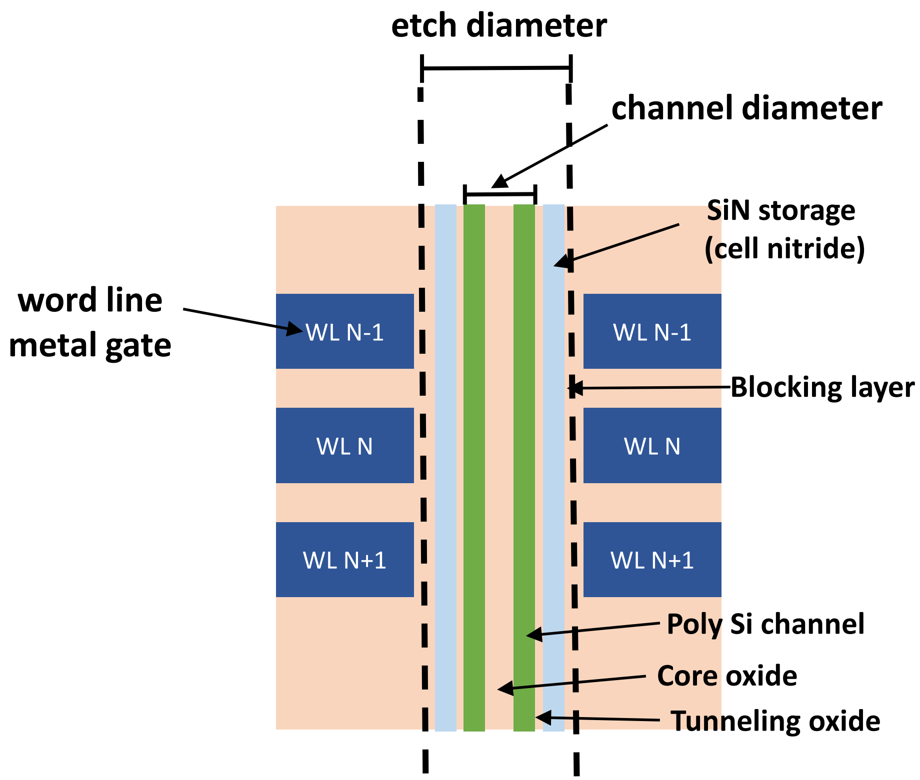
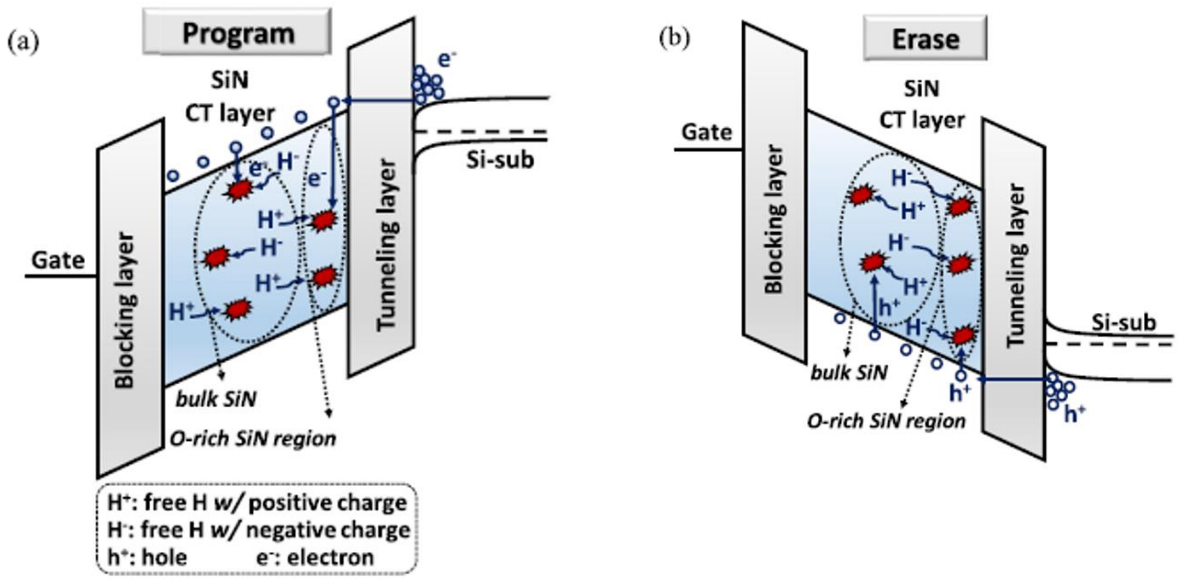
Free Hydrogen in NAND Cell Nitride Needs Process Control

Schematic of the charge trap NAND



Free H lateral migration under P/E operations

Degrade data retention for low-middle level cells → more error bits

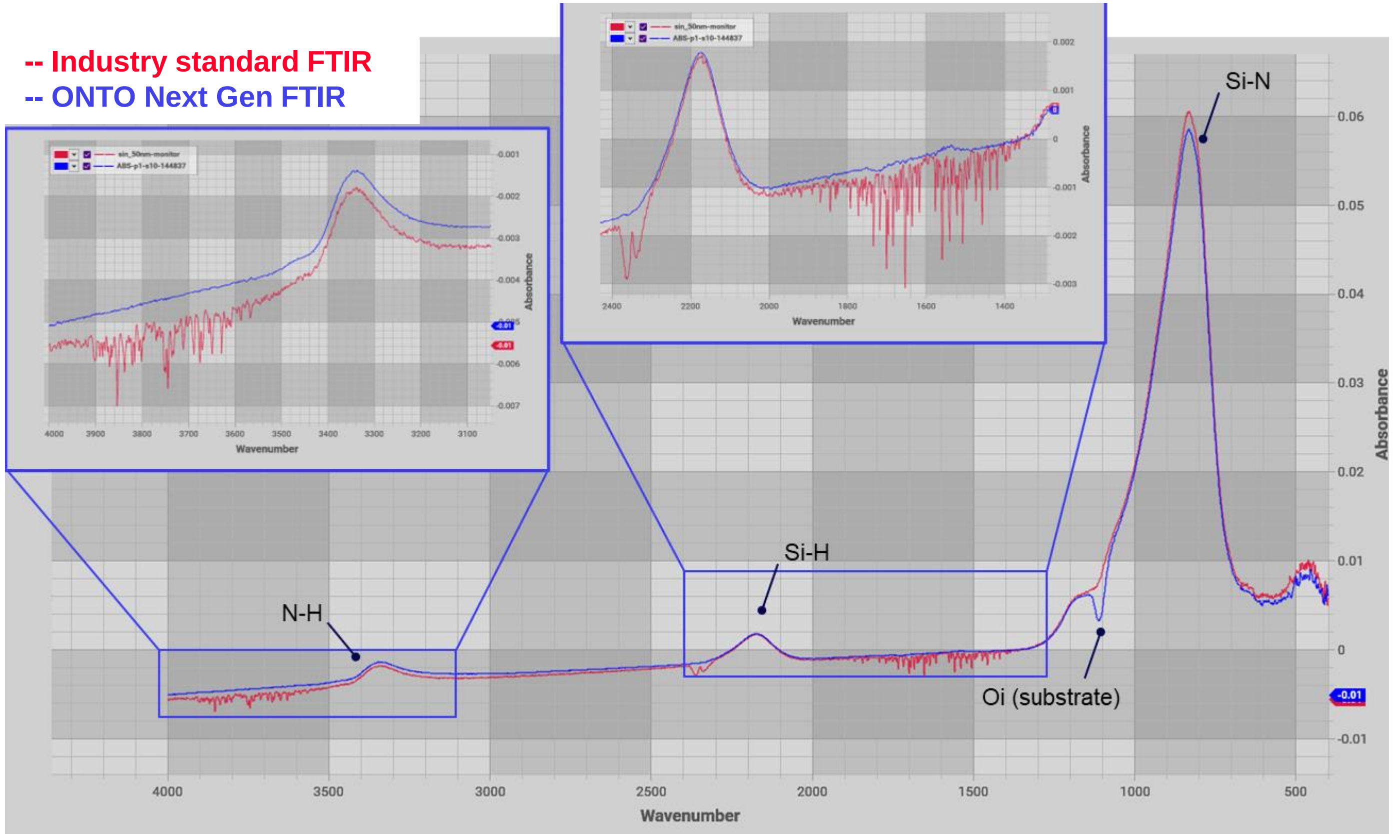


Wu et. al., "Atomistic study of lateral charge diffusion degradation during program/erase cycling in 3-D NAND flash memory." *IEEE Journal of the Electron Devices Society* 7 (2019): 626-631.

Improved SNR and Advanced Algo → Help Measure Thin Layers

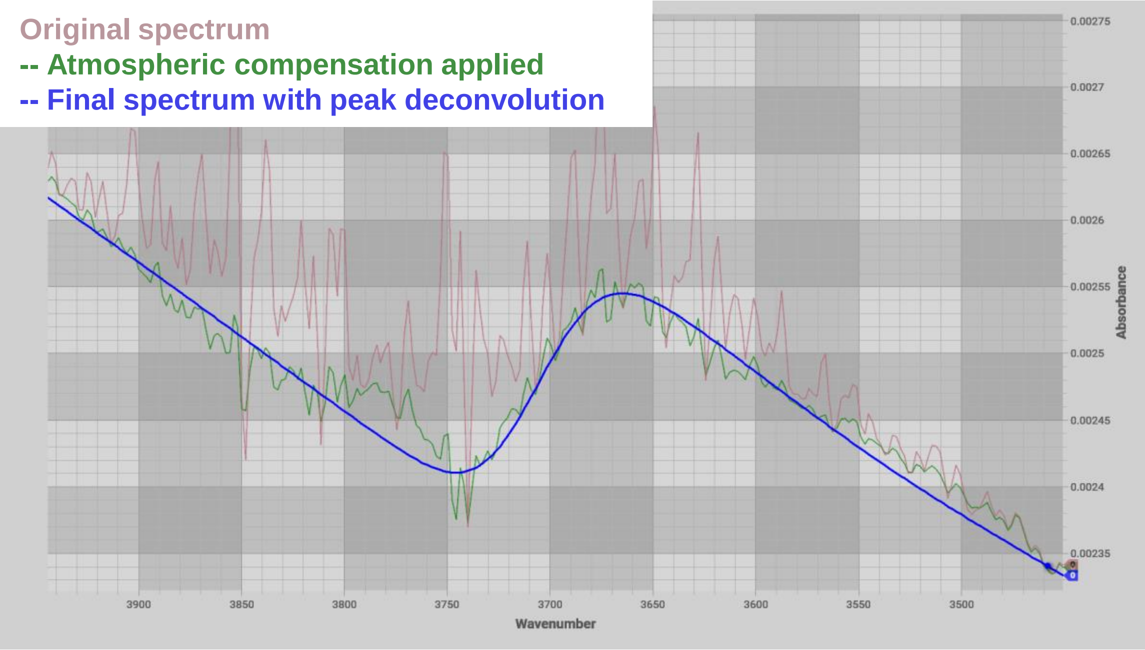
Improved SNR

especially at higher wavenumbers for a 50 nm SiN film



Atmospheric Compensation & Deconvolution

for the absorbance peak of SiOH on a 10 nm SiN layer



SiN FTIR Absorption Spectra of the Two Wafer Slots

- **Area of the Si-N peaks:**

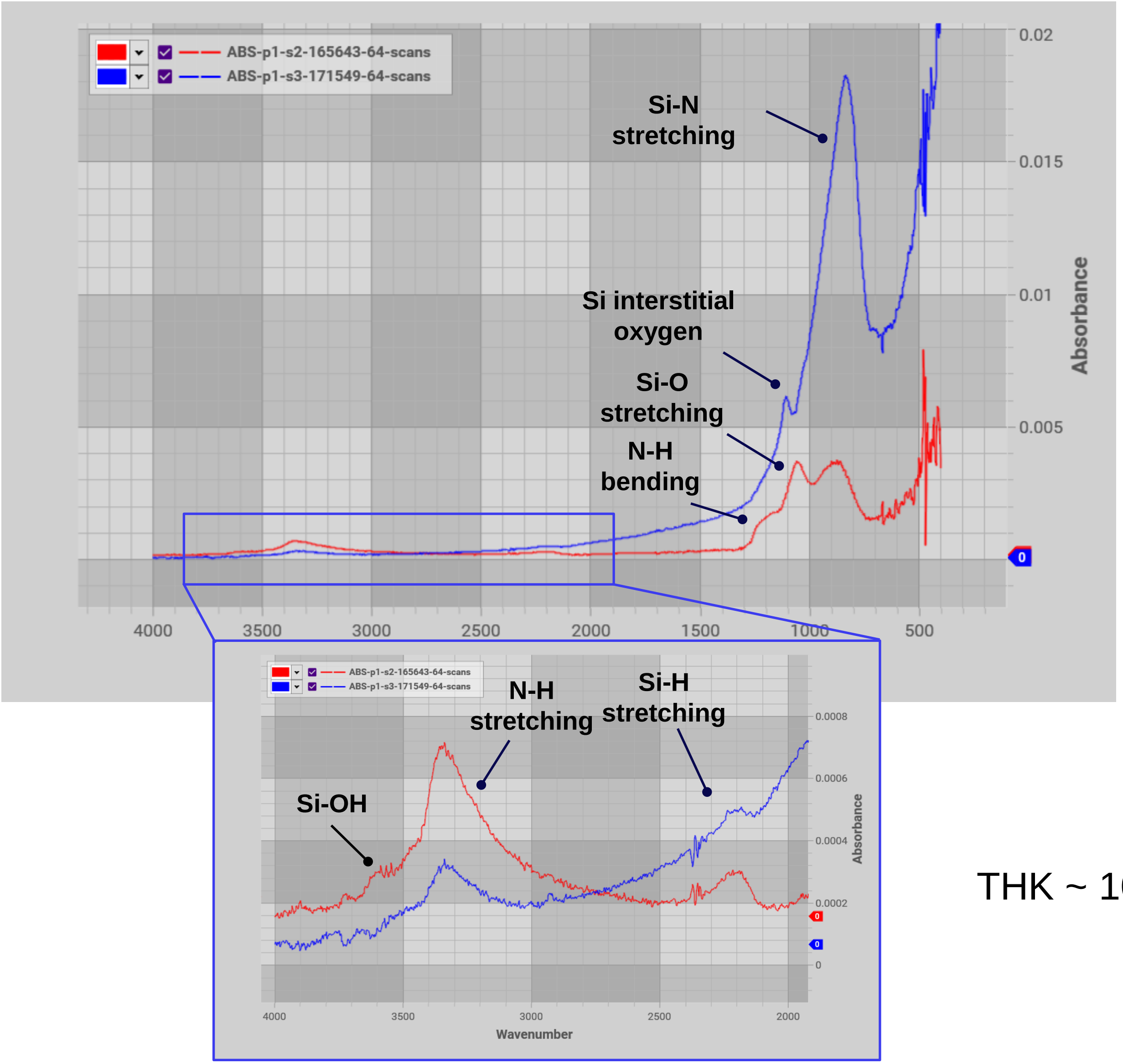
  S2 < S3, indicating that S2 is thinner than S3

- **Hydrogen-related peaks:**

  S2 > S3 (opposite of the above), indicating a much lower hydrogen level in S3, which has an improved process

- **Si-O peak:**

  S2 > S3, which is the same order as hydrogen level, indicating reduced oxidation incorporation in the S3 process.

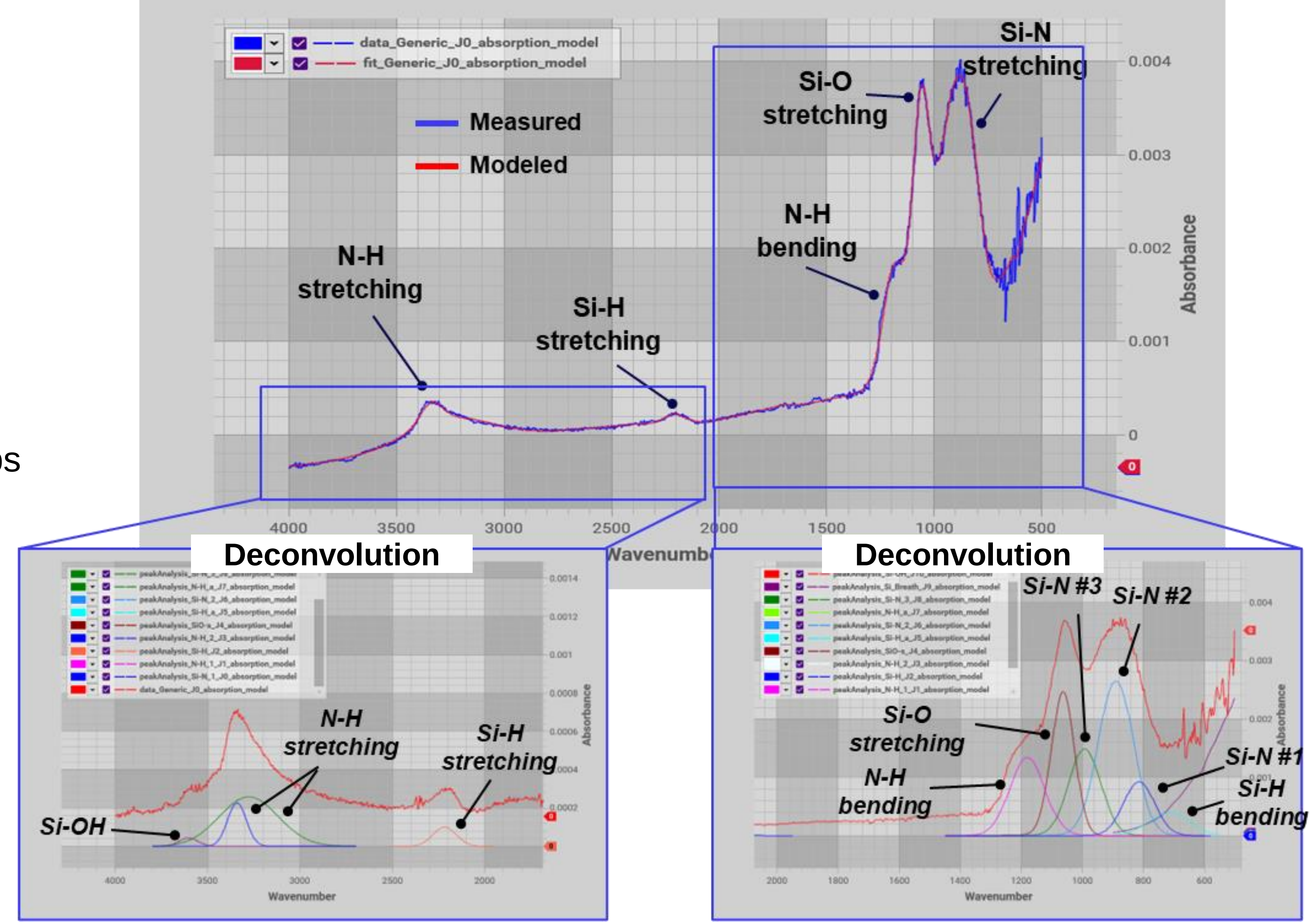


THK ~ 10 nm

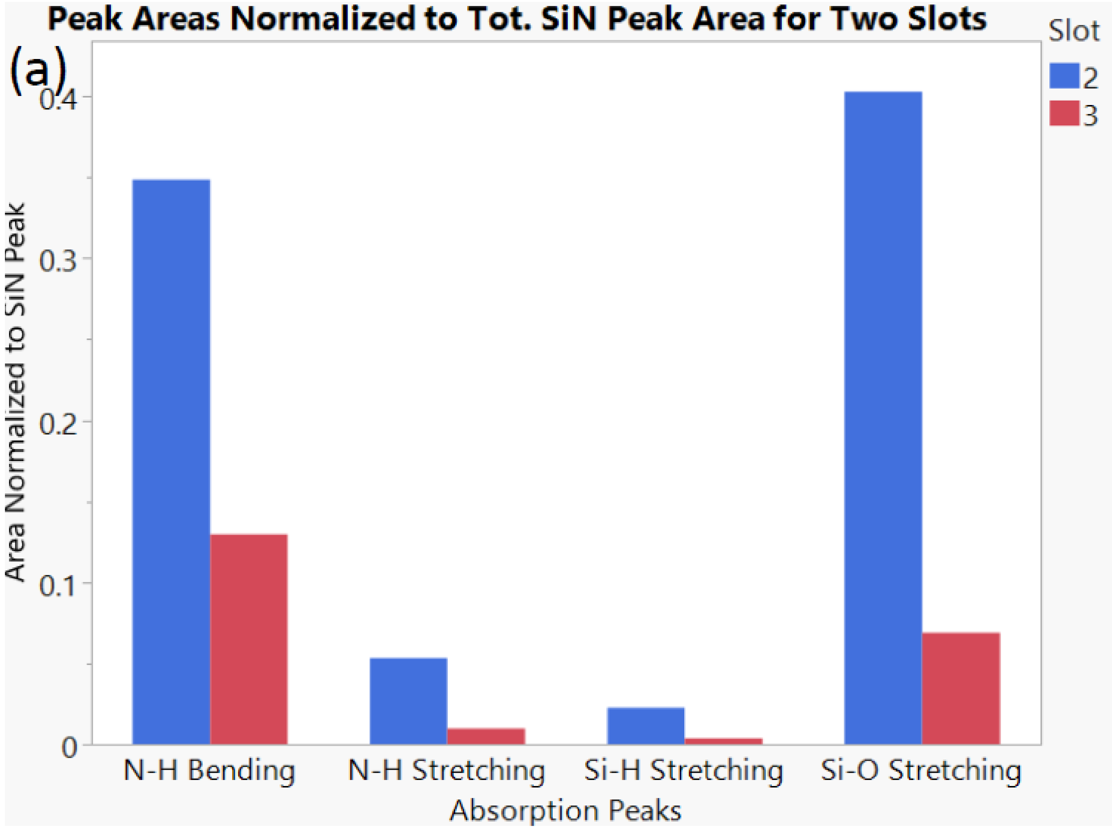
Deconvoluted SiN Spectra for Slot 2 and Optical Modeling

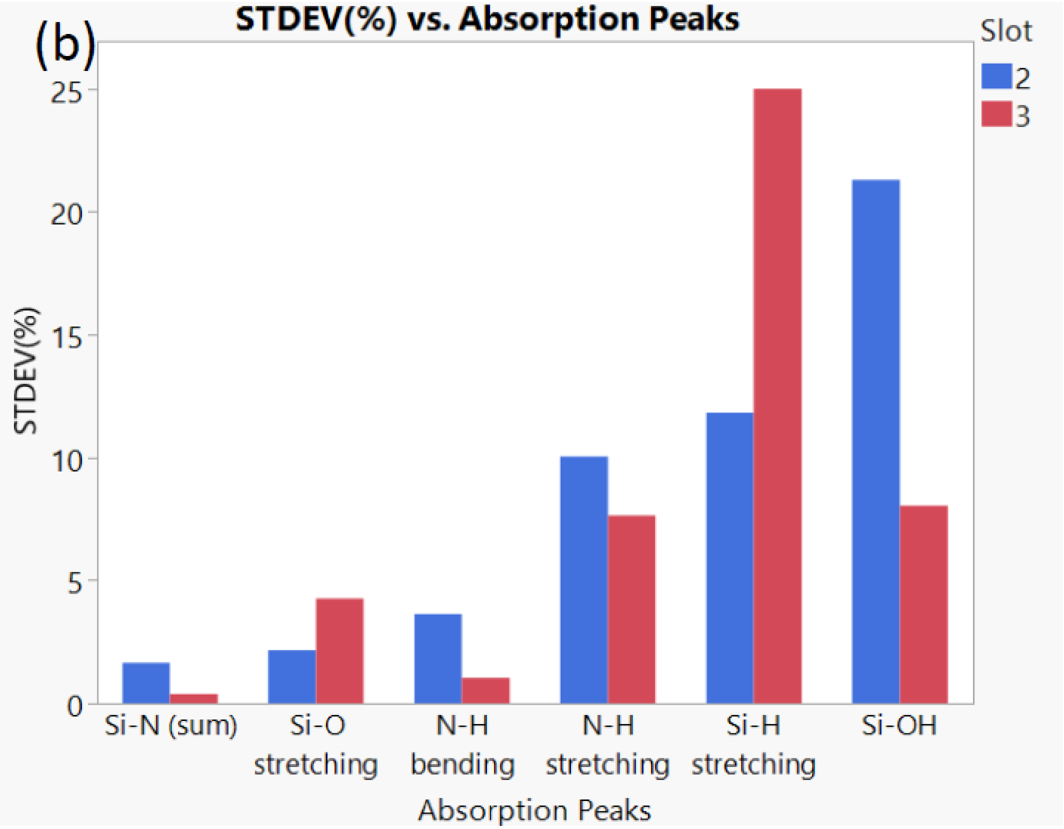
- Optical modeling takes into account of the optical constants consisting of Gaussian oscillators

- Deconvolution peak analysis evaluates associated peaks in groups within a specified wavelength range.



Clear DOE Separation and Good Repeatability





- ✓ **The N-H bending peak could be used as a metric for the H% owing to large area and good repeatability.**
- ✓ **Slot 3 having both lower H% and oxidation is an improved process**

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Use Case B: H% in a-C Process Control Wafers with DOE Skew

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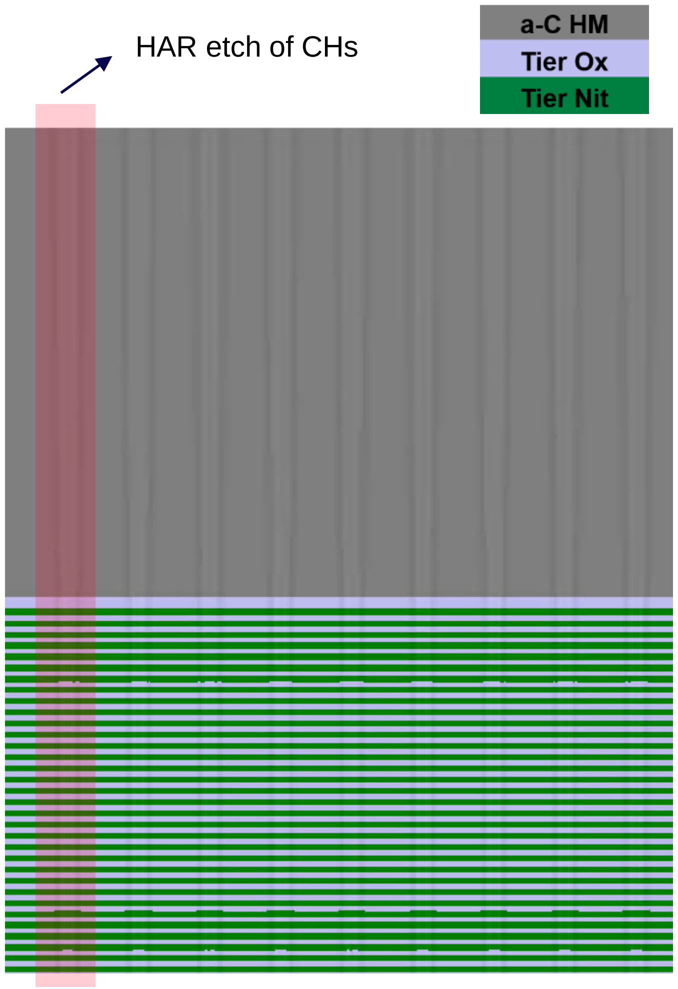
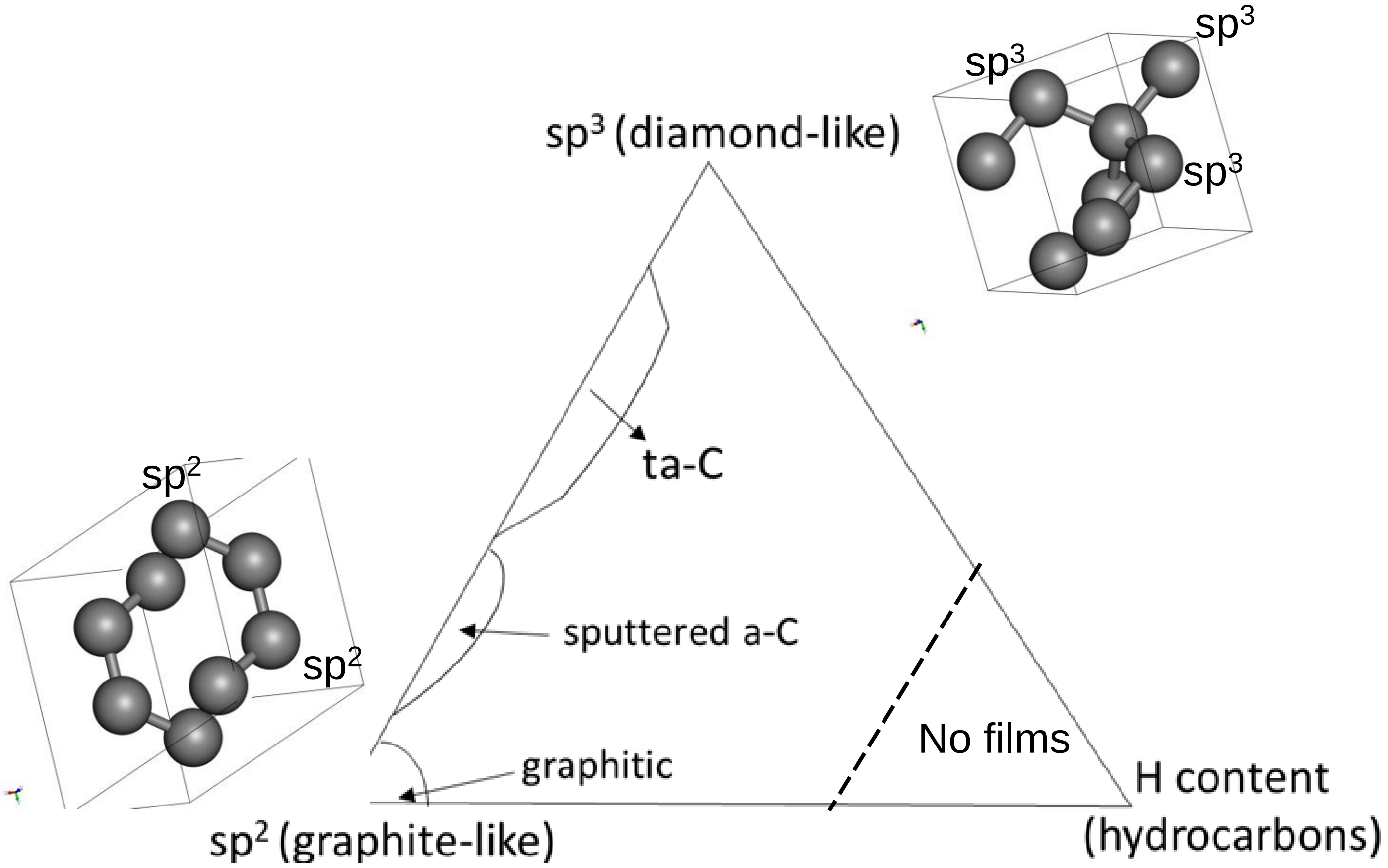
H% in a-C Hard Mask Affects Dry Etch Rates and Selectivity

Schematic of the a-C Hard Mask

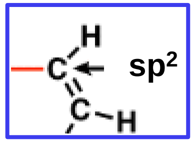


Ternary Phase diagram

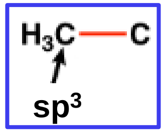
H% affects the chemical and mechanical properties of the mask, subsequently affecting etch rates and O/N selective ratio



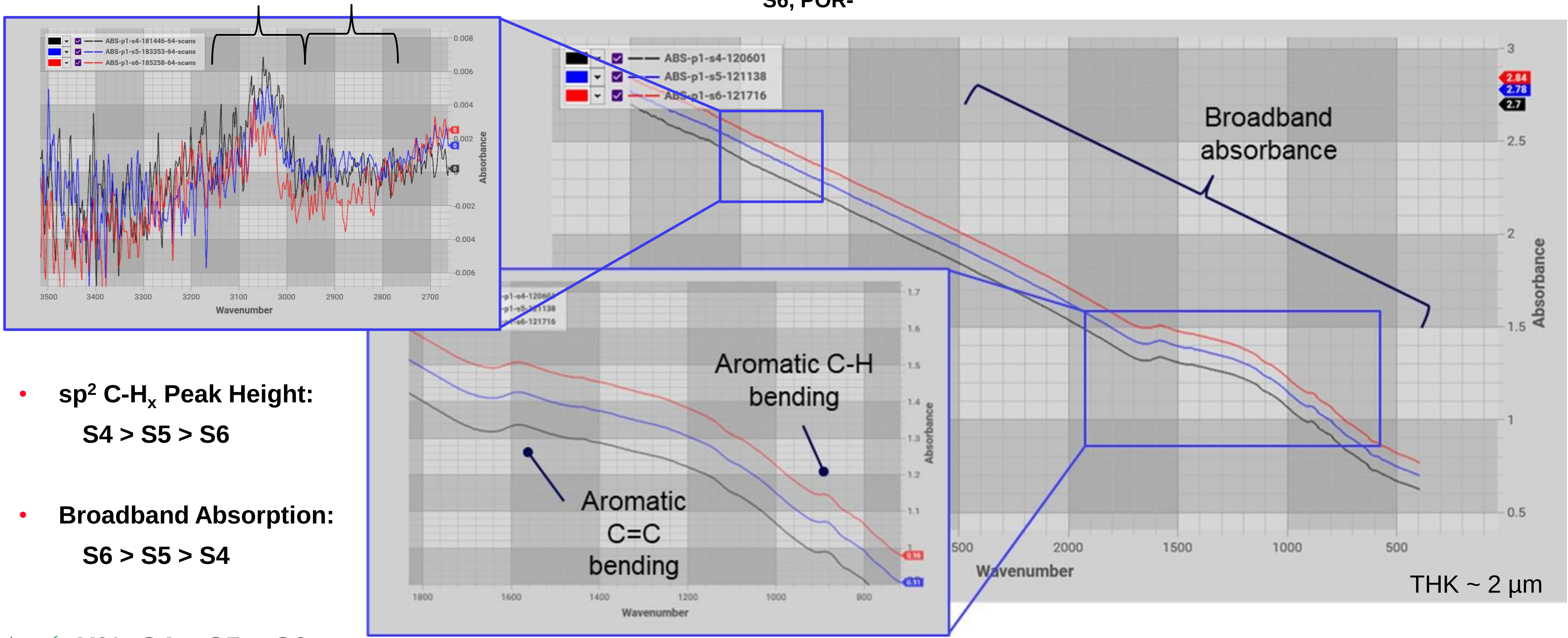
a-C FTIR Absorption Spectra of Skewed Wafers of Similar THK



sp² C-Hx sp³ C-Hx



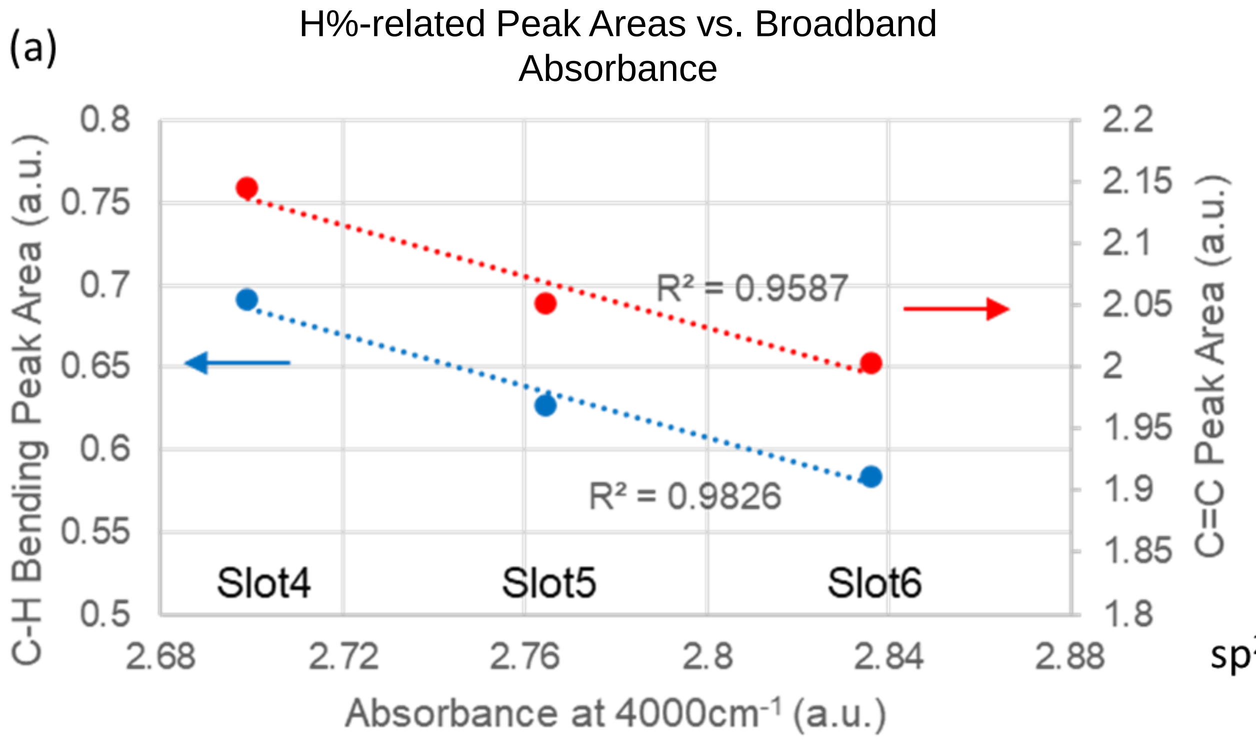
S4, POR+
S5, POR
S6, POR-

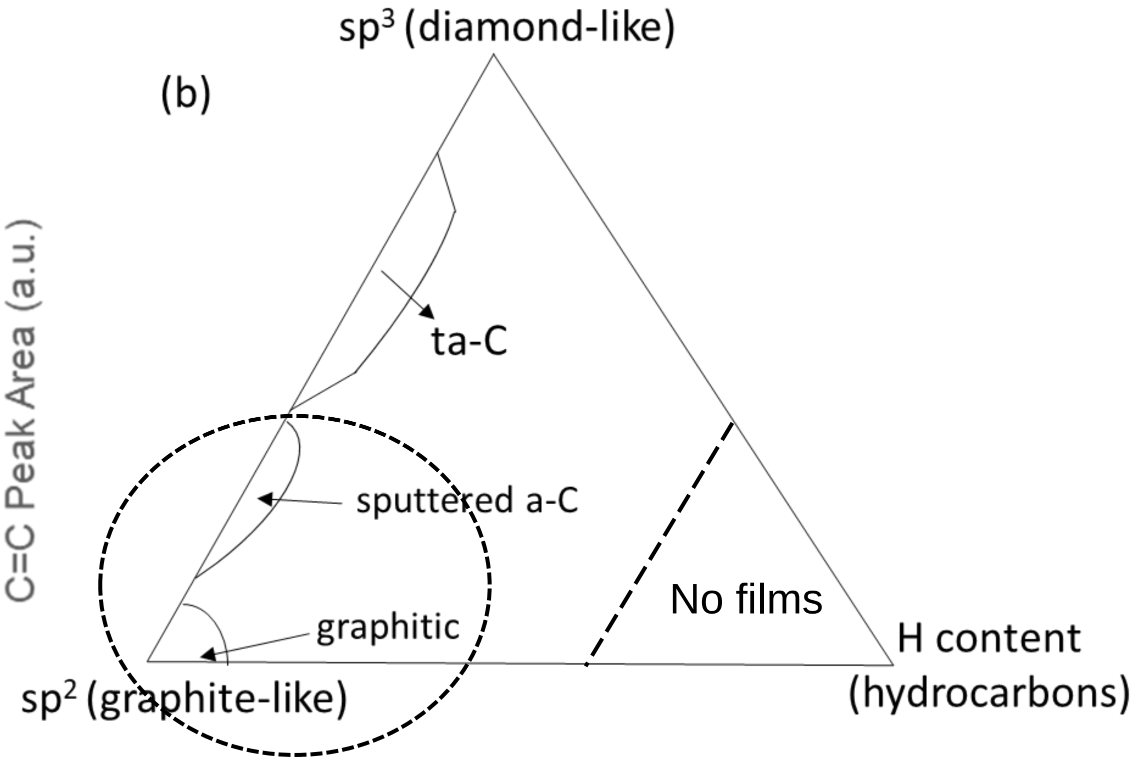


- **sp² C-Hx Peak Height:**
  S4 > S5 > S6
- **Broadband Absorption:**
  S6 > S5 > S4

✓ **H%: S4 > S5 > S6**

Linear Relations in Accordance with the Skew and Phase Diagram





- **Both C=C and C–H bonding (result of H-incorporation):**

  S4 > S5 > S6

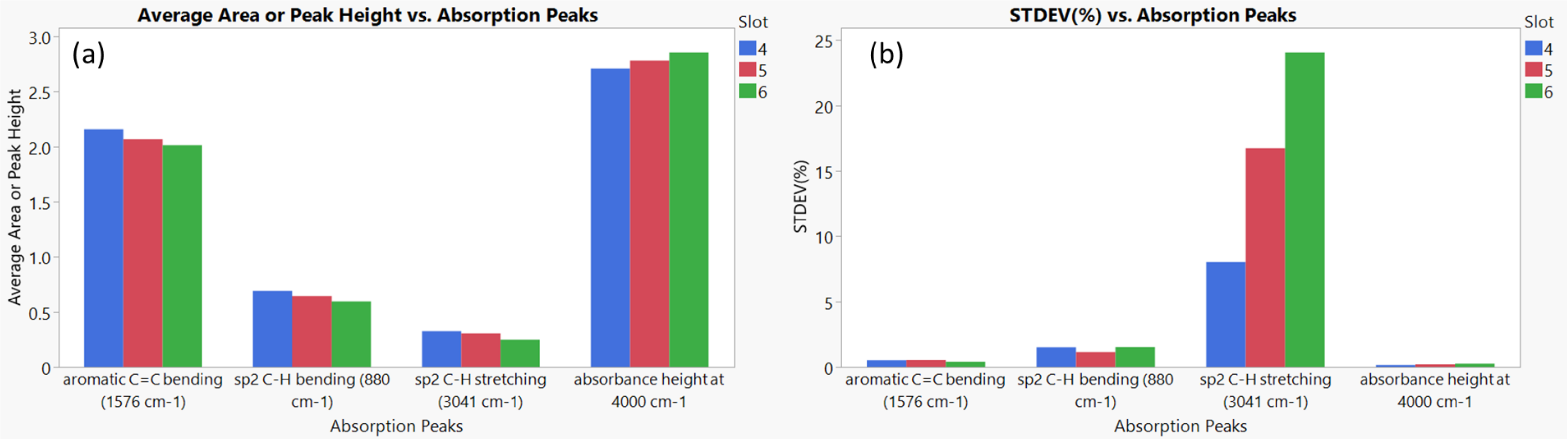
✓ H%: S4 (POR+) > S5 (POR) > S6 (POR-)

- **Broadband absorption (closeness to the lower left corner of the phase diagram):**

  S6 > S5 > S4

Clear DOE Splitting and Good Repeatability

H%: S4 (POR+) > S5 (POR) > S6 (POR-)



✓ **Aromatic C=C bending or the sp² C-H bending peak could be used as a metric of H% owing to large peak areas and better repeatability.**

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Conclusions

- FTIR peak deconvolution and optical modeling can precisely quantify the H-related chemical bonds in both thin SiN (~ 10 nm) and thick a-C (~ 2 µm).

- For thin-layer SiN, the Si-H stretching, N-H stretching, and Si-O stretching peaks show a clear distinction in two wafer slots with different processes. In the optimized process, we observed not only a reduction in hydrogen content but also a substantially lower oxidation level in the film.

- For a-C, the observed high broadband absorbance is correlated with low hydrogen content and high sp^2 carbon bonding, consistent with the phase diagram and hydrogen content skew conditions in three wafer slots. The acquired hydrogen content data can be utilized to predict and correlate with selective etch rates and the mechanical properties of the hard mask film.

- Through automated peak analysis, FTIR measurement offers a pathway for inline monitoring and dynamic process tuning by enabling timely adjustments based on the observed chemical compositions.

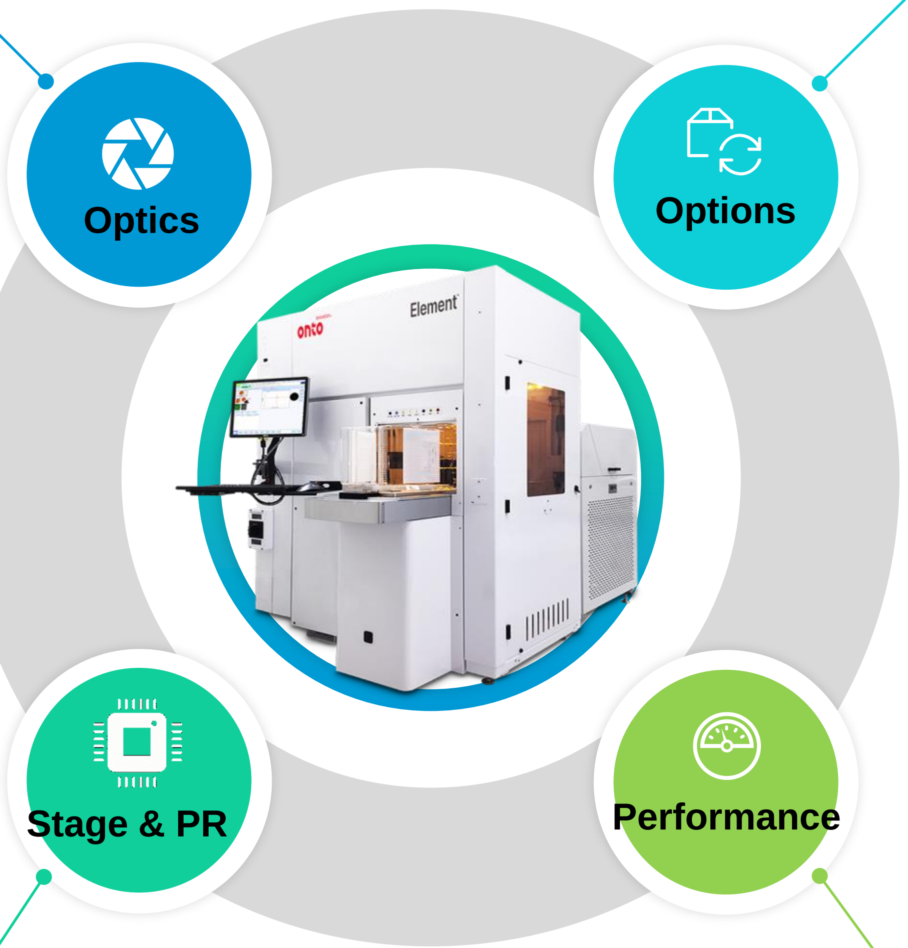
ONTO Next Gen FTIR Tool: Summary of New Improvements

Redesigned Optics for 2mm IR Spot

- High temperature SiN IR light source
- High IR windows with 2x transmission
- High D* detector with optimized response
- Customized elliptical mirrors
- **< 2mm circular IR spot on sample**
- Longer lifetime HeNe laser
- Advanced modelling & analytics
- Newly designed Adv. Optics Board
  - 64bit Windows 10
  - Higher 24bit ADC
  - Onboard data processing
  - Onboard diagnostics and extendibility

- **High Res rotary stage encoder with um level accuracy and repeatability**
- 3um stage accuracy (vs 10um on prev gen)
- 1mm field of view adv. Pattern Rec.
- Inline monitoring patterned wafer

Stage Encoder and Pattern Rec



Options and Configurations

- DTGS or LN2 cooled MCT detector
- 1 or 2 loadports
- E84 OHT
- Light curtain or protection bar
- 3 or 4 light lamp tower
- On stage Au/FZ calibration target

- **EPI**
  - **< 1mm EE for EPI**
  - **20% higher Tput**
  - **2x better precision**
- **CO**
  - **< 2mm EE**
  - **2x higher Tput for CO**
  - **20% better precision**
- **7x better SNR compared with previous gen**

Superior Performance

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Acknowledgements and References

Collaborators

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Onto:
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- Zhuo Chen
- Cong Wang
- Benoit Ravot

Selected References that Helped Interpretation

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– Ferrari, Andrea C., and John Robertson. "Interpretation of Raman spectra of disordered and amorphous carbon." *Physical review B* 61.20 (2000): 14095.

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– Expanded Material Metrology For Refined Etch Selectivities (semiengineering.com)

– Advanced Modeling In FTIR Offers New Applications For HVM (semiengineering.com)

Thank You

谢谢 | 謝謝

ありがとう

Obrigado

Danke

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Merci

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