Pre SiGe Wet Cleans Development for sub 1x nm Technology Node

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Background

- Due to higher aspect ratio features observed in advanced technology nodes (1x nm and smaller), the epi growth uniformity suffers across wafer
- Carbon, fluorine and oxygen residues incoming from post etch and ashing steps degrade the surface cleanliness and inhibit the epitaxial growth = missing epi defects
- Need C, O and F at low levels simultaneously going into epi deposition

Objective

- Improve pre-Epi wet cleans to ensure a pristine surface suitable for uniform epitaxial growth
- Ensure wet cleans equipment is not contributing to WiW non-uniformity

1

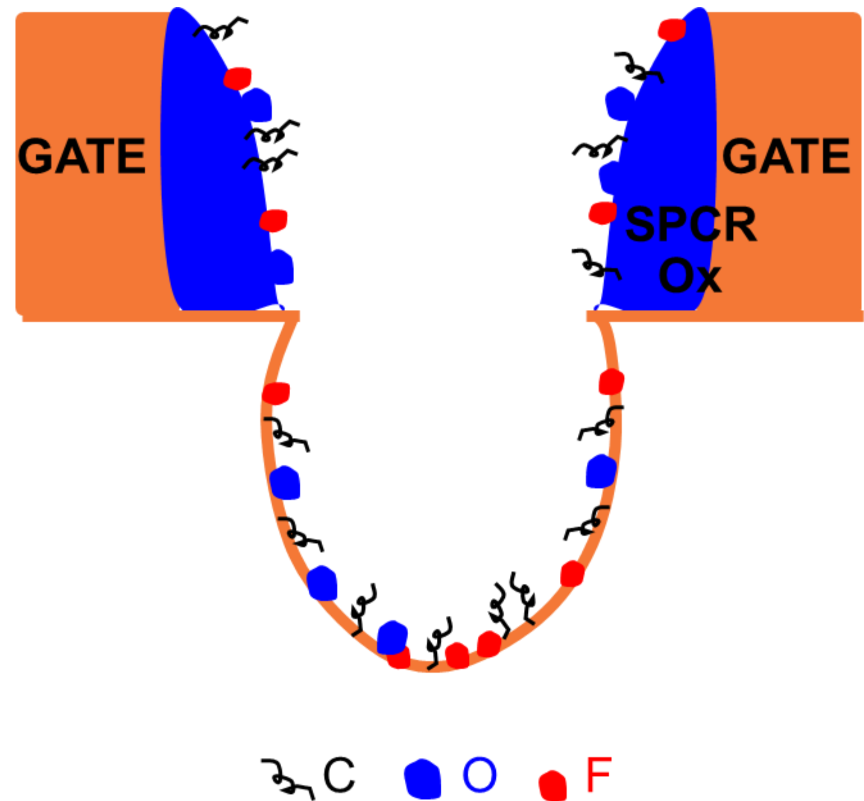
Achieving Pristine Wafer Surface with Pre-Epi Wet Clean

2

Improving Cavity Size WiW Uniformity

Sub 1x nm HVM Requirements for Pre-EPI Wet Cleans

- POR wet cleans are two-step cleans (back to back)
- HVM Requirements:
  - Eliminate carbon, fluorine and oxygen residues from cavity and SPCR Ox
  - SPCR Ox loss is minimal (= limited dHF usage in wet clean steps)
  - Retain cavity shape and size
  - Zero WiW non-uniformity



Pre-EPI Wet Clean Splits and XPS Results

Atomic Conc. (Normalized)

a — POR two step wet clean baseline (POR)

b — POR with shorter queue time (Process A)

Not Shown

c — DIO_3 based HF last wet clean (Process B)

Not Shown

d — DIO_3 based clean with upstream etch process changes (Process C)

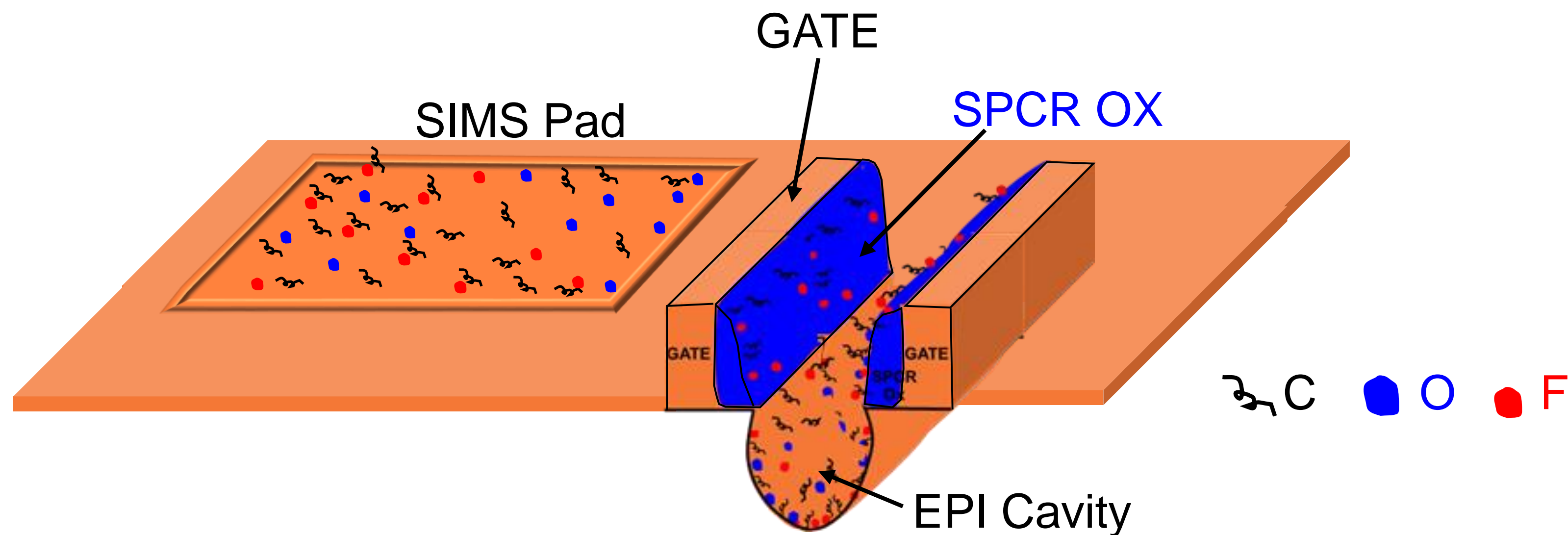
Not Shown

0_Incoming | 1_After_Pre_CLN1 | 2_After_Pre_CLN2

Process

Sub 1x nm HVM Requirements for Pre-EPI Wet Cleans

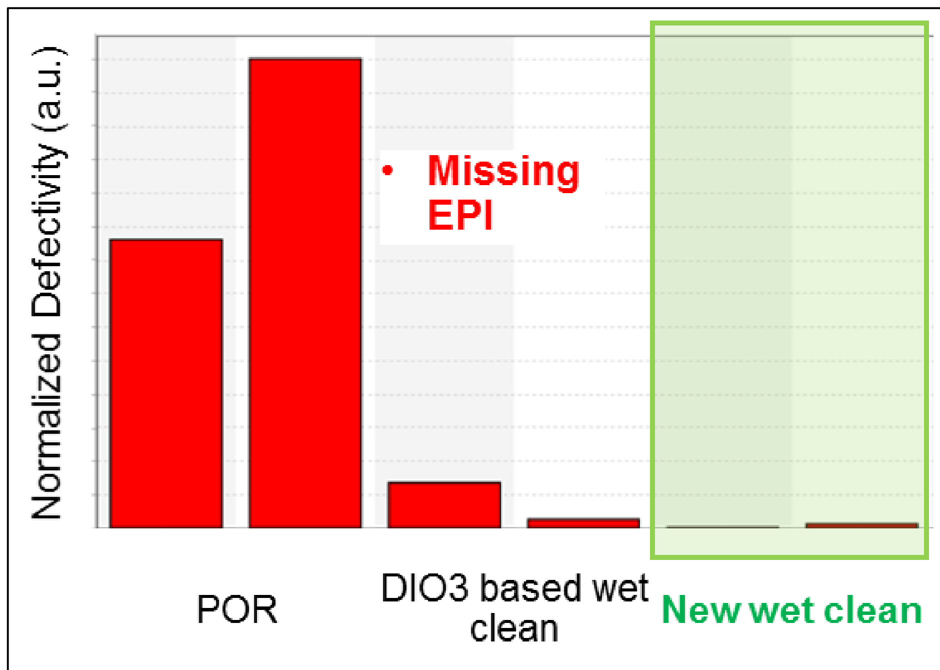
- ❑ DIO_3 based wet clean did not lower missing epi defectivity to required levels

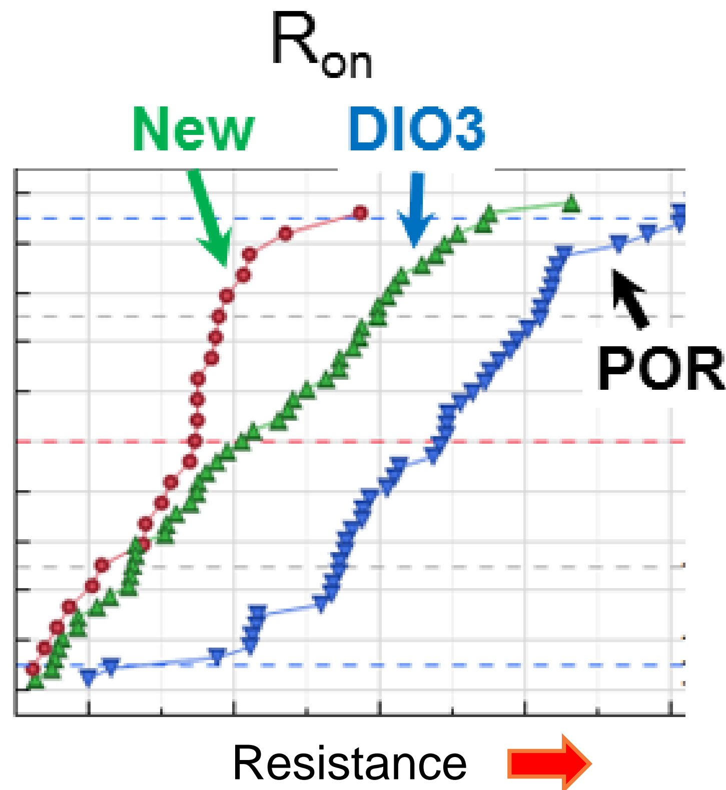


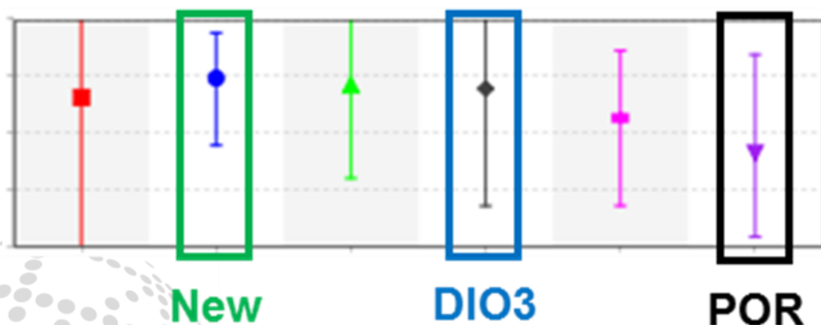
- ❑ SIMS pad measurements not reflective of C, O and F removal from SPCR Ox and epi cavity

☞ Therefore, we had to develop a new pre-epi wet clean

Results from 1st Split Lot



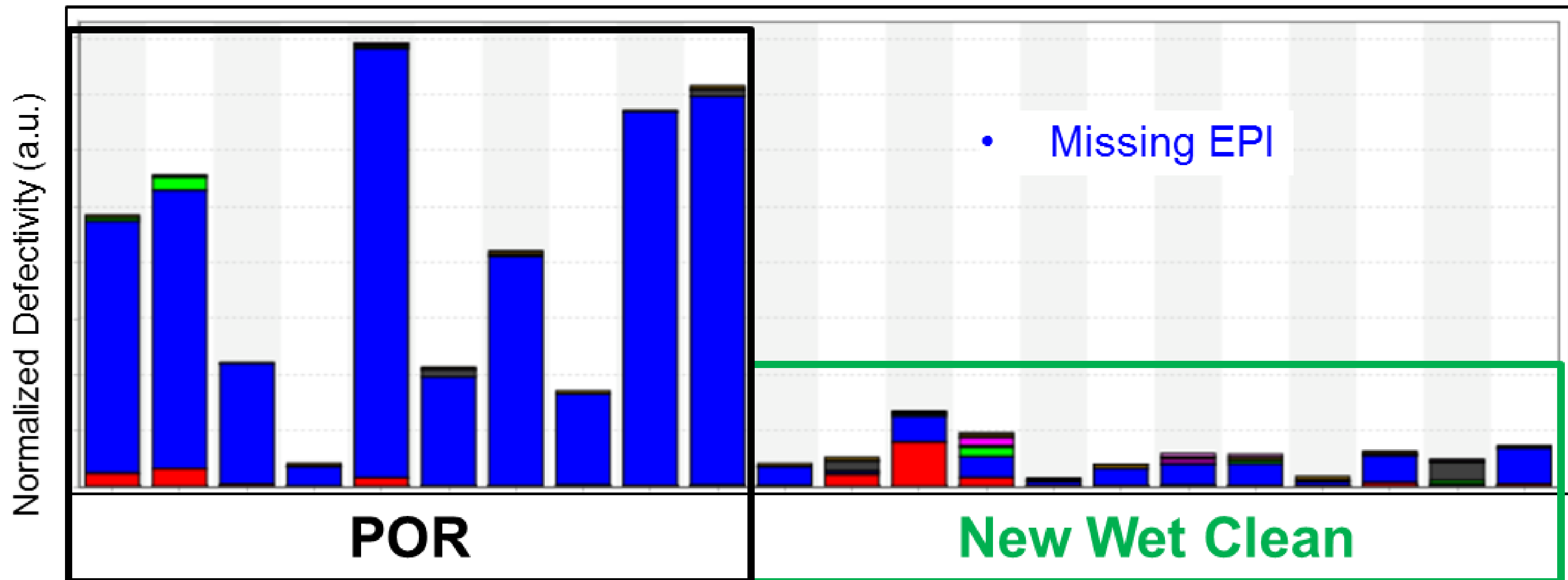




- **New pre-epi wet clean**
  - R_{on} ⇩ to largest extent with New wet clean
  - Cavity size is unchanged
  - ~ 50x ⇩ in missing epi defects

Post Implementation Results

SPC chart for Missing Epi after implementation as POR



- **New Pre-Epi Wet Clean**
  - Accomplished with no change in SPCR dimension from old POR
  - Pristine wafer surface required additional changes in upstream processes
  - Further optimization in progress

1

Achieving Pristine Wafer Surface with Pre-Epi Wet Clean

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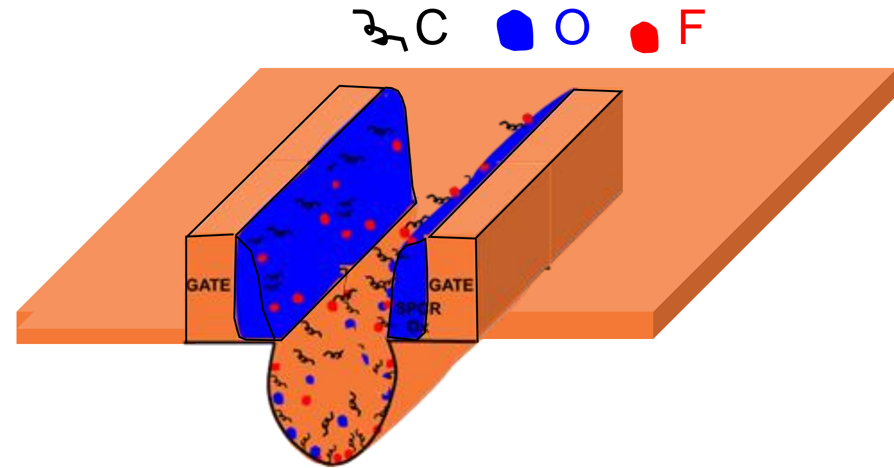
Improving Cavity Size WiW Uniformity

Need for WiW Uniformity Improvement

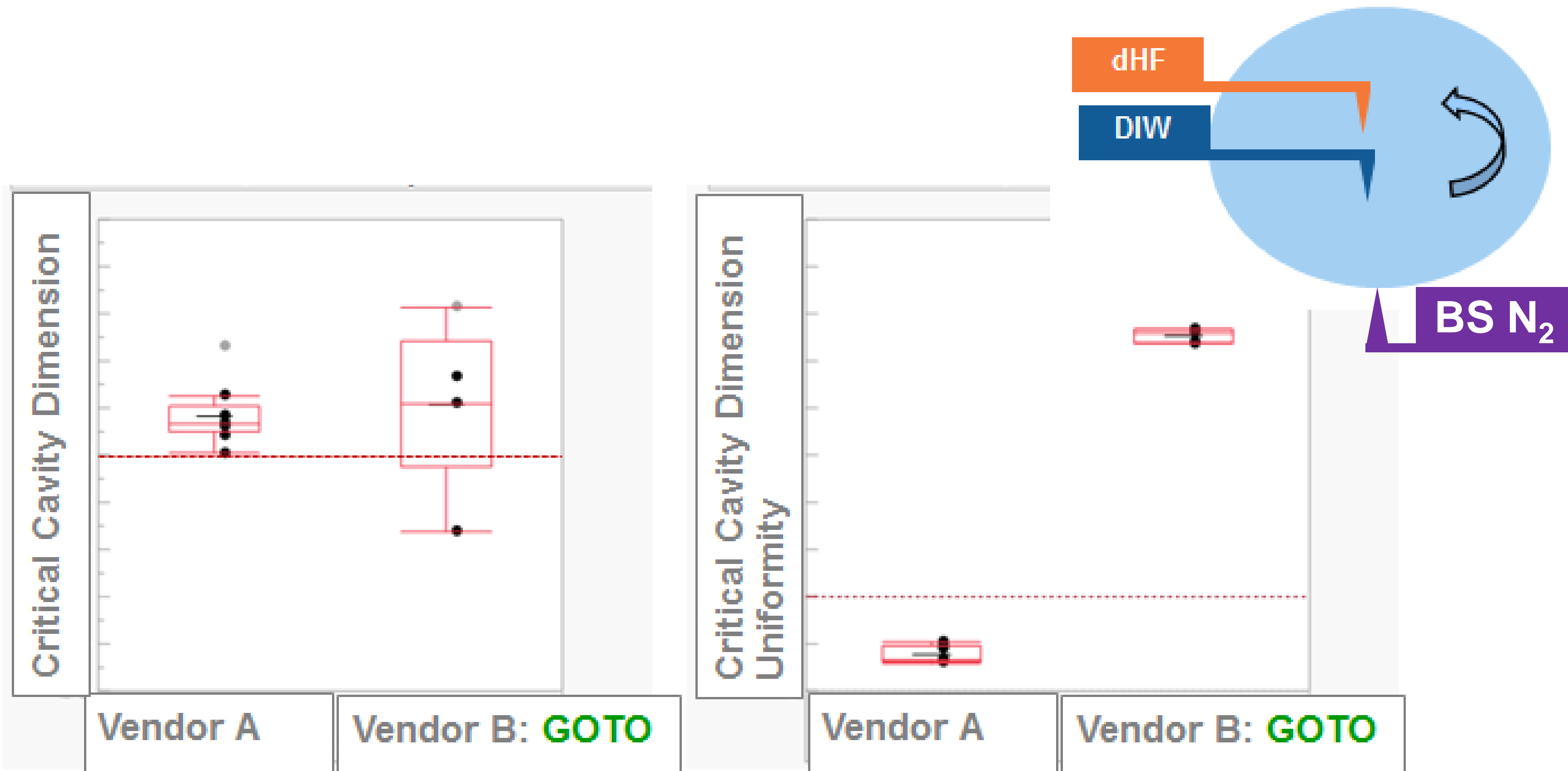
- In sub 1x nm wet cleans, the pre-epi wet clean requires complete post etch residue removal and precise partial removal of SPCR Ox while leaving the rest of the exposed oxide and other materials intact



- Pre-epi wet clean step done with dHF /IPA drying on single wafer clean SNK does not meet cavity size WIW uniformity process specifications

- Hence, a decision was made to transfer this critical clean step to a different wet clean vendor toolset, from Vendor A to Vendor B

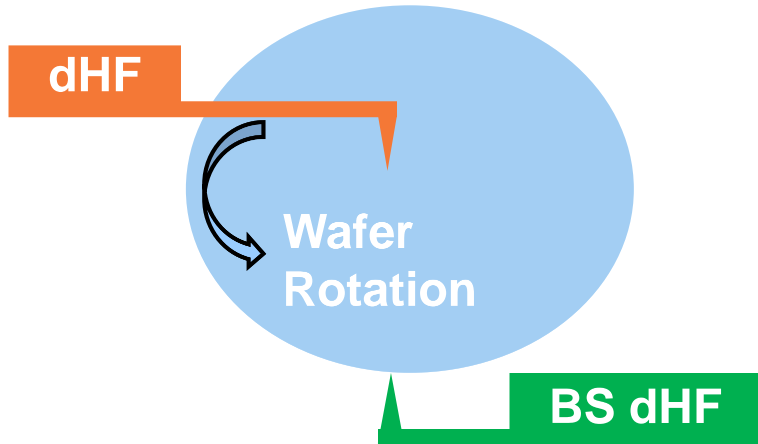
Improving WiW Uniformity: Adding BS N_2



- Adding N_2 to wafer backside in vendor B tool gave worse performance

- Need to change process/ hardware/ software settings in GO TO tool to ⇩ WiW non-uniformity

Improving WiW Uniformity: Adding dHF on Wafer BS



- Had to increase FS dHF time to match removal in Vendor A tool
- *Generating many BS particles with dHF only on wafer BS*

Vendor B: GOTO

FS dHF Process time

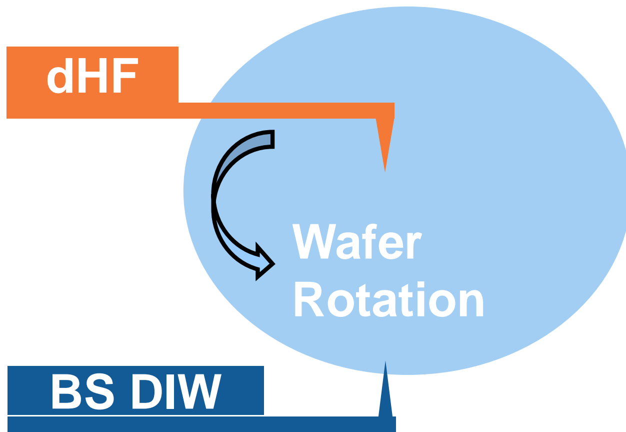
Critical Cavity Dimension

POR | With BS dHF for different FS dHF times

Critical Cavity Dimension Uniformity

POR | With BS dHF for different FS dHF times

Improving WiW Uniformity: Adding DIW on Wafer BS



Vendor B: GOTO

FS dHF Process Time

Critical Cavity Dimension

POR

With BS DIW for different FS dHF times

Critical Cavity Dimension Uniformity

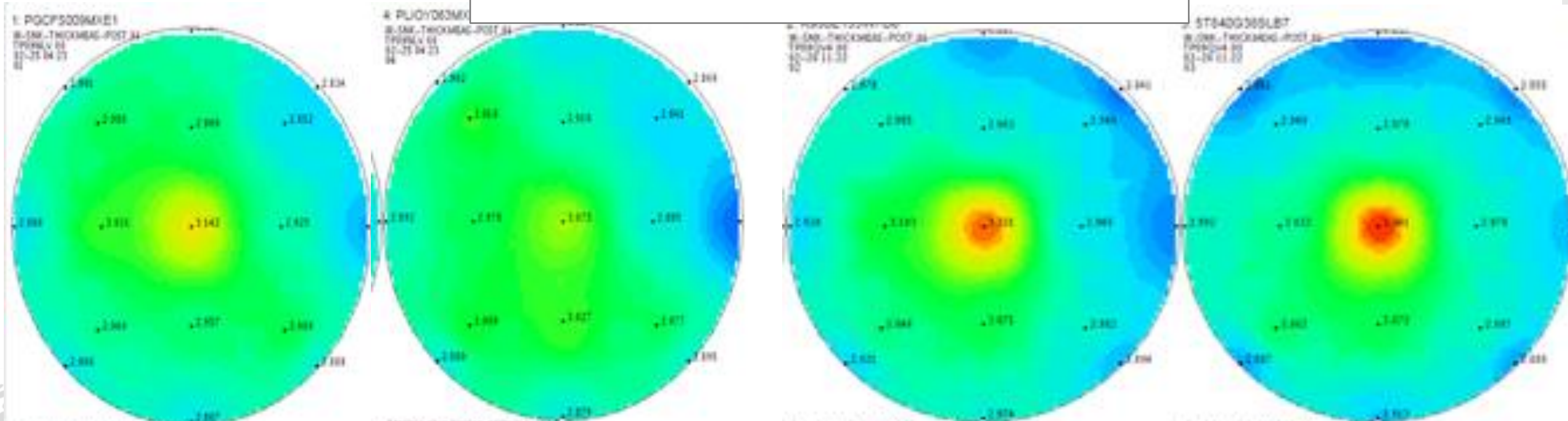
POR

With BS DIW for different FS dHF times

- With FS dHF and BS DIW process, only process time needs to be dialed in to achieve target critical cavity dimension

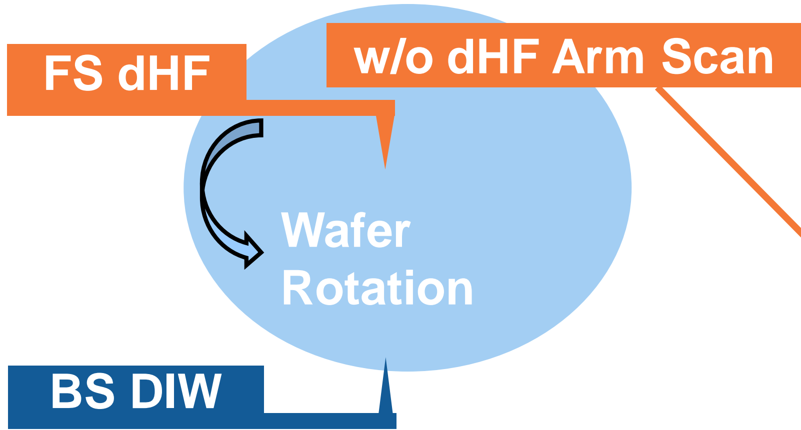
Improving WiW Uniformity: Effect of Flow on Wafer BS

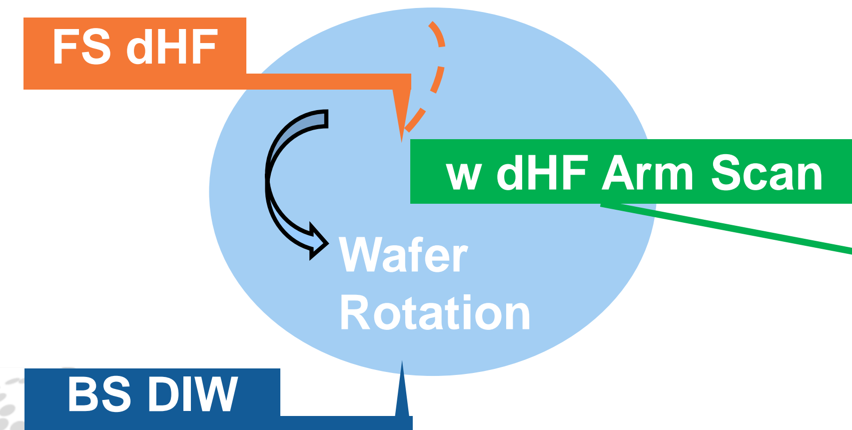
Blanket OX Test Wafer Data Shown



- BS dHF is generating excessive removal on wafer FS!

Improving WiW Uniformity: Adding DIW on Wafer BS + FS dHF scan





Vendor B: GOTO

Critical Cavity Dimension

POR

With BS DIW and no FS dHF arm scan

With BS DIW *and* FS dHF arm scan

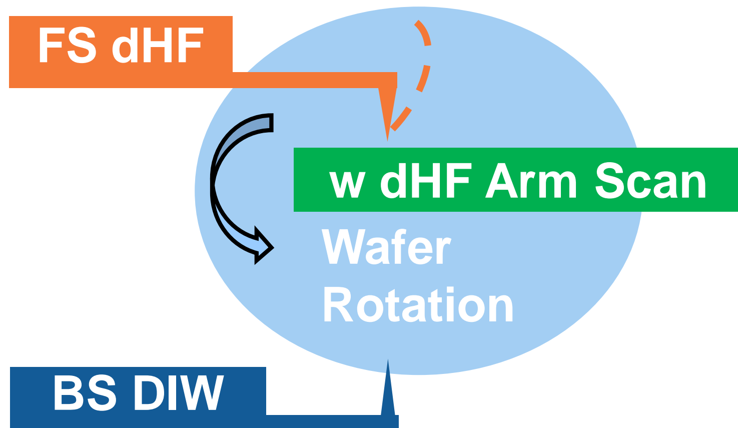
Critical Cavity Dimension Uniformity

POR

No FS dHF arm scan

FS dHF arm scan

Final HVM Setting on Vendor B Tool



HVM LEARNINGS:

- Need to change process time to match critical cavity dimension achieved on Vendor A tool
- Adding BS flow makes WiW temperature uniform on wafer FS
- For wafer BS, recommend using DIW, than dHF, to prevent BS particle generation and center removal signature
- Need chemical dispense arm scan to minimize WiW non-uniformity

Summary

- DIO_3 based clean with upstream etch process changes gave the lowest C, O and F contamination levels on the XPS pad but does not reflect reality
- Developed a new pre-epi wet clean that:
  - ⇩ R_{on} (same measured for not shown transistor metrics such as DIBL, I_{eff} etc.)
  - Cavity size is unchanged
  - ~ 50x ⇩ in missing epi defects
  - Further optimization is in progress
- To meet cavity size WiW uniformity requirements, had to transfer wet clean process to new vendor SNK
  - Adding BS flow makes WiW temperature uniform on wafer FS
  - For wafer BS, recommend using DIW, than dHF, to prevent BS particle generation and center removal signature
  - Need chemical dispense arm scan to minimize WiW non-uniformity

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- Integration, Device and, TCAD

Thank You

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