Novel STI Step-height Uniformity Control by Wet Etch Process in 4xnm CMOS Device

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Outline

❖ Introduction

- HARP & HDP materials characteristic comparison
- The importance of step height uniformity control
- STI HARP wet etching uniformity performance by liquid HF

❖ Step Height Uniformity Improvement

- Annealing effect
- Liquid HF (LHF) & gas HF (GHF) etching mechanism
- Process optimization result

❖ Conclusion

STI Materials Comparison (HDP & HARP)

❖ High aspect ratio process (HARP) has been applied in shallow trench isolation (STI) for 45nm CMOS and beyond due to better gap fill ability.

◆ STI (Shallow Trench Isolation) Material Road Map

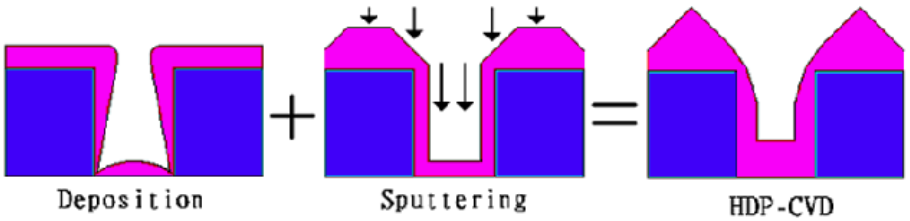
Generation		130 nm	65 nm	55 nm	4x nm	2x nm
HDP	A/R<4					
HARP	A/R~6					

◆ HDP (High density plasma):

✓ Precursor: SiH_4 (silane)

Reaction equation :

$SiH_4 + 2O_2 + Ar \xrightarrow{\text{Heat , RF}} SiO_2 + 2H_2O + Ar + \ldots$

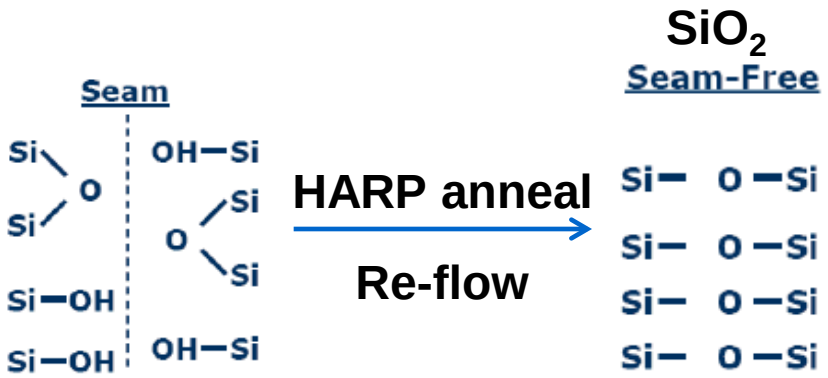


✓ SiO_2 cross-linking **before** annealing

✓ Poor gap fill ability (A/R<4)

◆ HARP (High aspect ratio process):

✓ Precursor: O_3 + TEOS ($Si(OC_2H_5)_4$)



✓ SiO_2 cross-linking **after** annealing

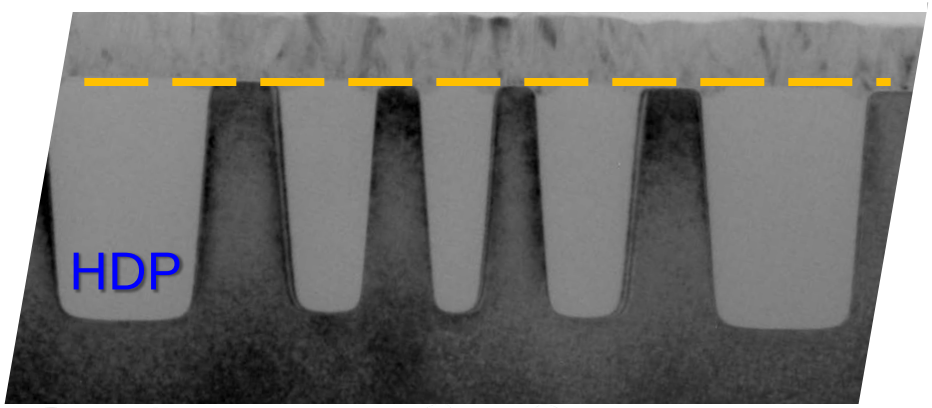
✓ Better gap fill ability (A/R~6)

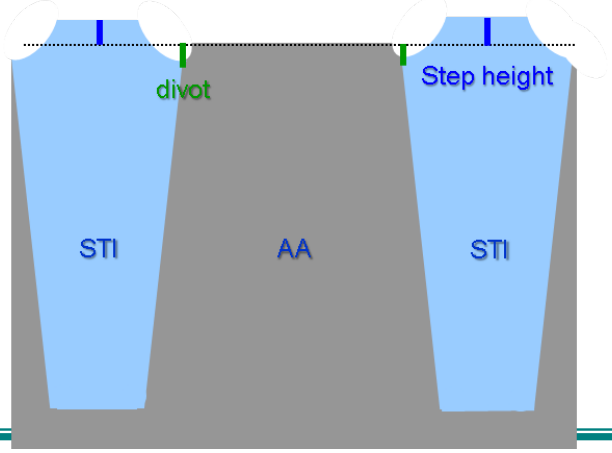
Worse Etch Uniformity of HARP by LHF

❖ HARP wet etching rate (E/R) is harder to be controlled than HDP in different STI width by conventional liquid HF (LHF).

◆ **HDP :**

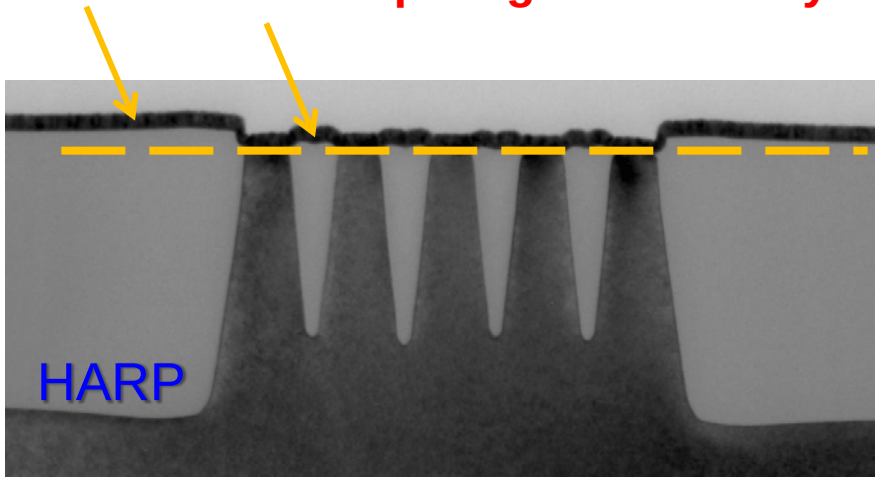
✓ **Good step height uniformity**





◆ **HARP:**

✓ **Worse step height uniformity**

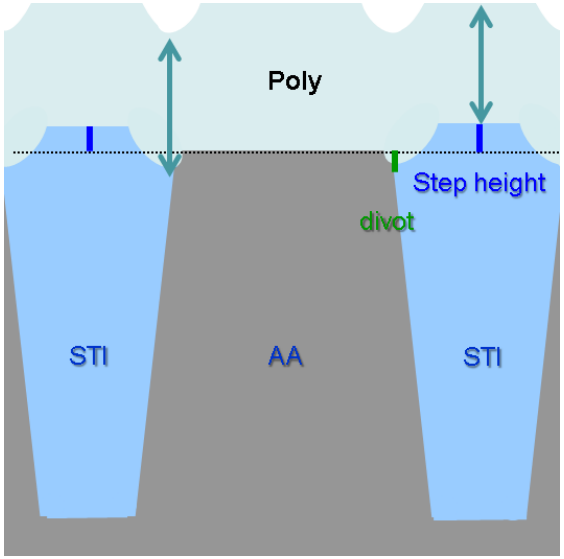


Powerchip The Definition & Importance of Step height & Divot

❖ Step height control is necessary to avoid poly residue issue and Y% loss.

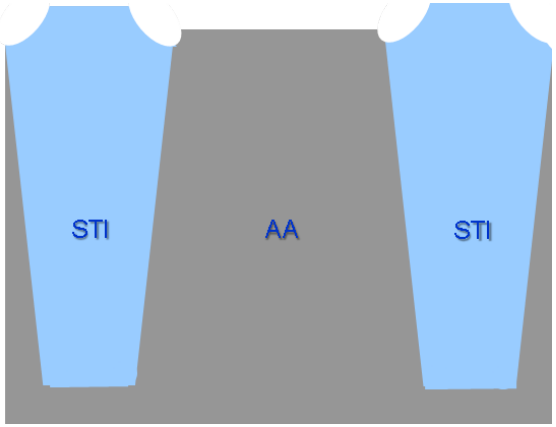
Before poly gate etch → **After poly gate etch**

Case1:

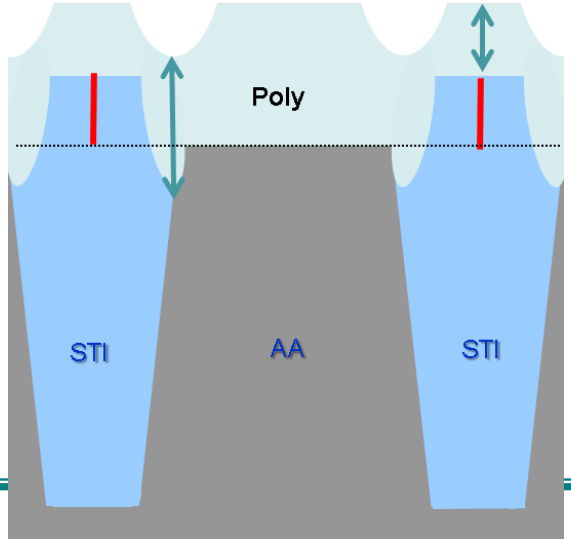


Low Step height
or
Shallow Divot

Poly residue free

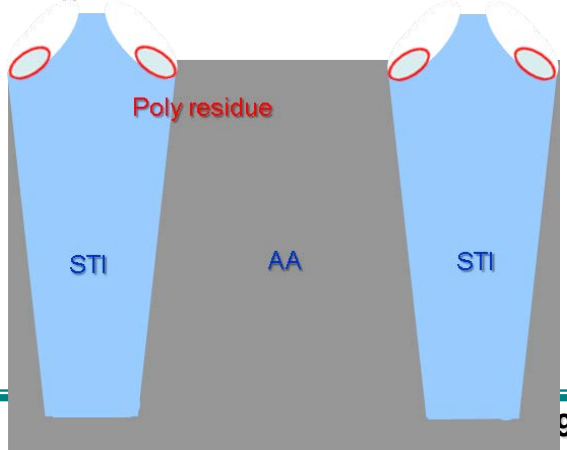


Case2:



High Step height
or
Deep Divot

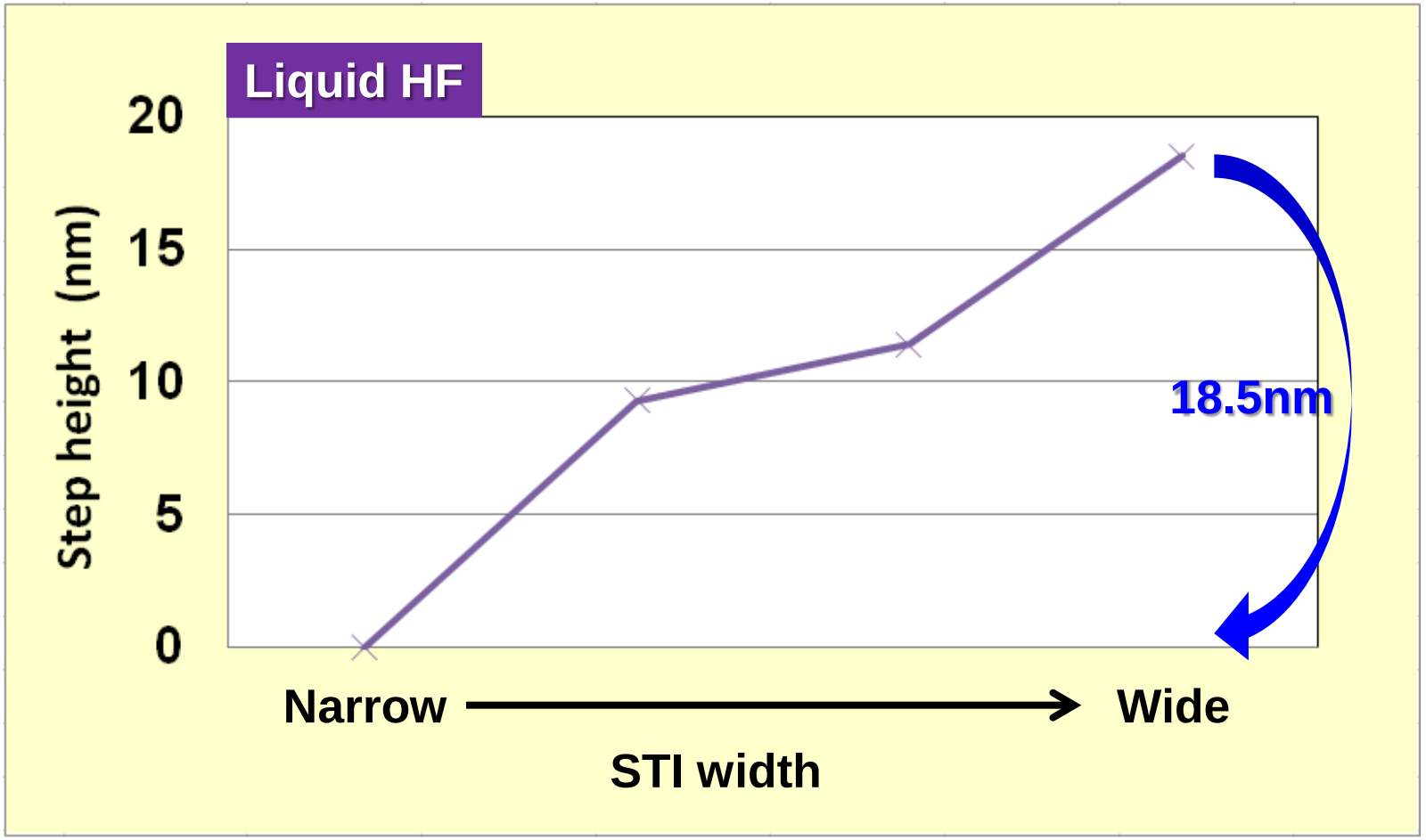
Poly residue➔ Y% killer



Worse Step height Uniformity by LHF

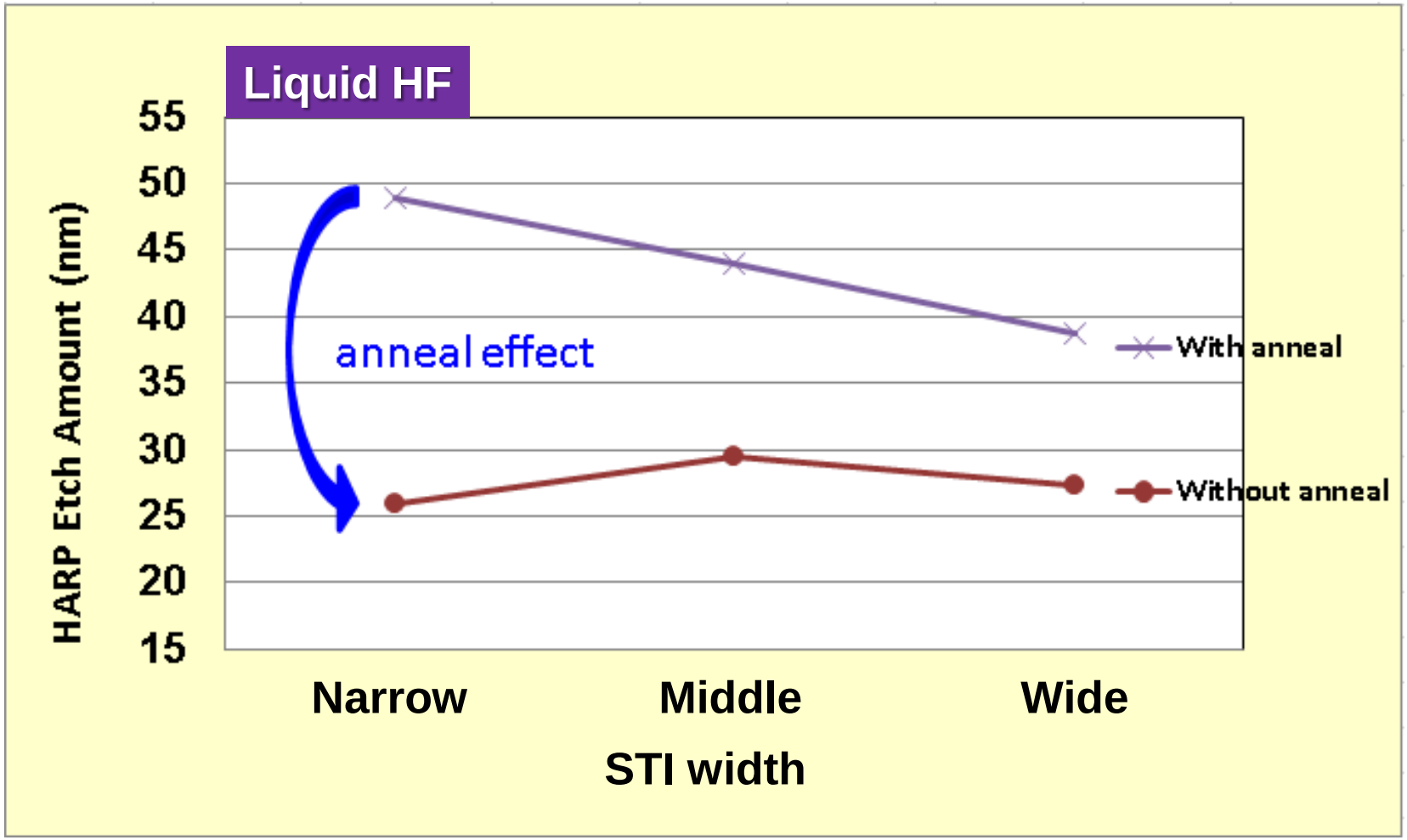
❖ Step height (S/H) uniformity in different STI width is worse under LHF etching during well implant and gate oxide formation process.

❖ S/H in narrow STI width is lower than wide one and the bias is18.5nm.



Anneal Effect on Wet Etch Uniformity

- Annealed HARP quality is different from narrow to wide STI width.
- Etch amount (E/A) uniformity is worse in annealed HARP than without annealed one.



Annealed HARP Quality in Different STI Width

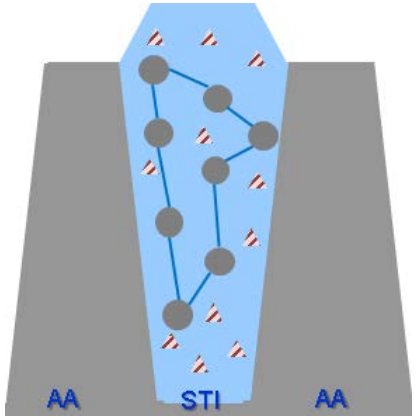
- Narrow STI width area: weak cross-linking & high impurity.
- Wide STI width area: strong cross-linking & low impurity.

Weak Cross-linking

High Impurity

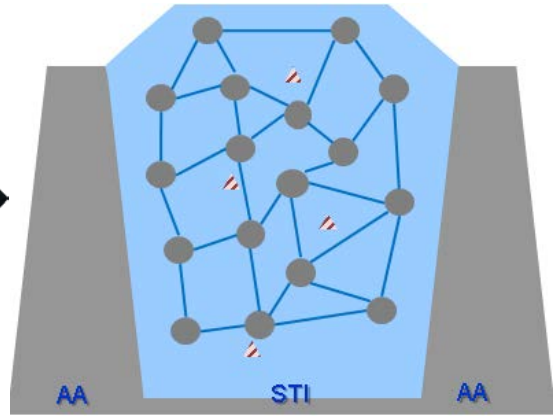
Strong Cross-linking

Low Impurity



STI width

Narrow → **Wide**



LHF (hardness dominate)

E/R

Fast → **Slow**

GHF (diffusion dominate)

Slow → **Fast**

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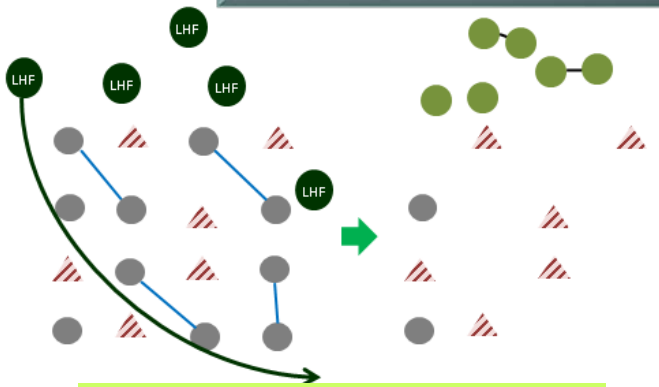
LHF & GHF Etching Mechanism

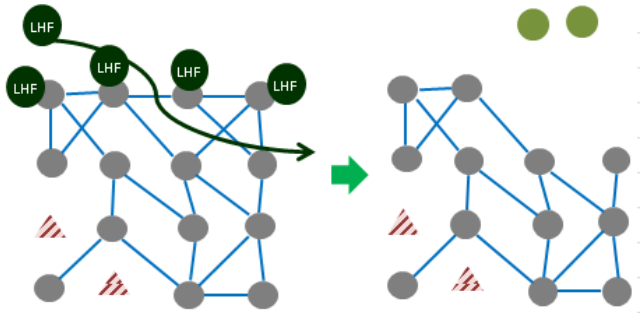
- LHF: HARP cross-linking (hardness) dominate.
- GHF: gas diffusion is limited by HARP impurity.

STI width Narrow → Wide

LHF (Si-O-Si De-bonding)

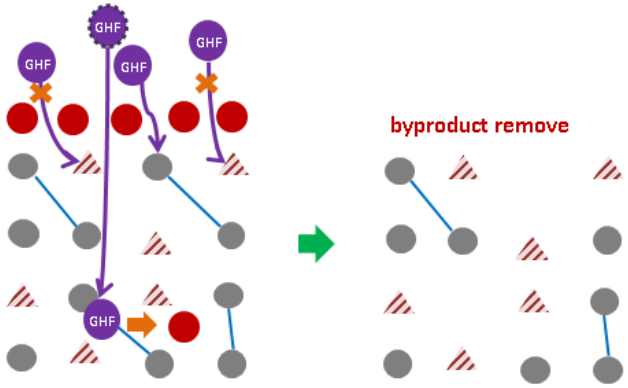


Weak cross-linking ➔ E/R fast

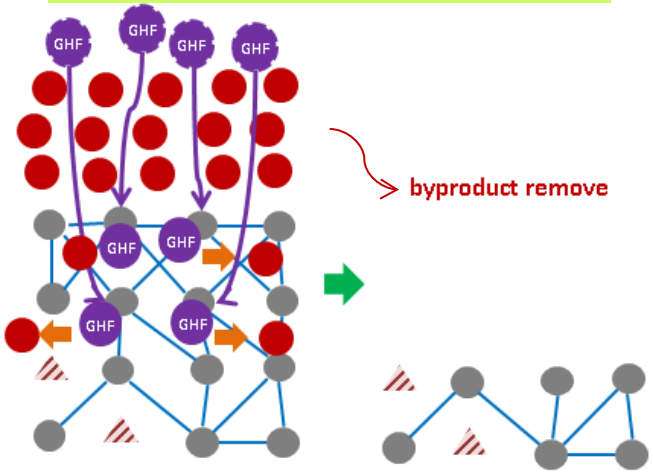


Strong cross-linking ➔ E/R slow

GHF (gas diffusion reaction)



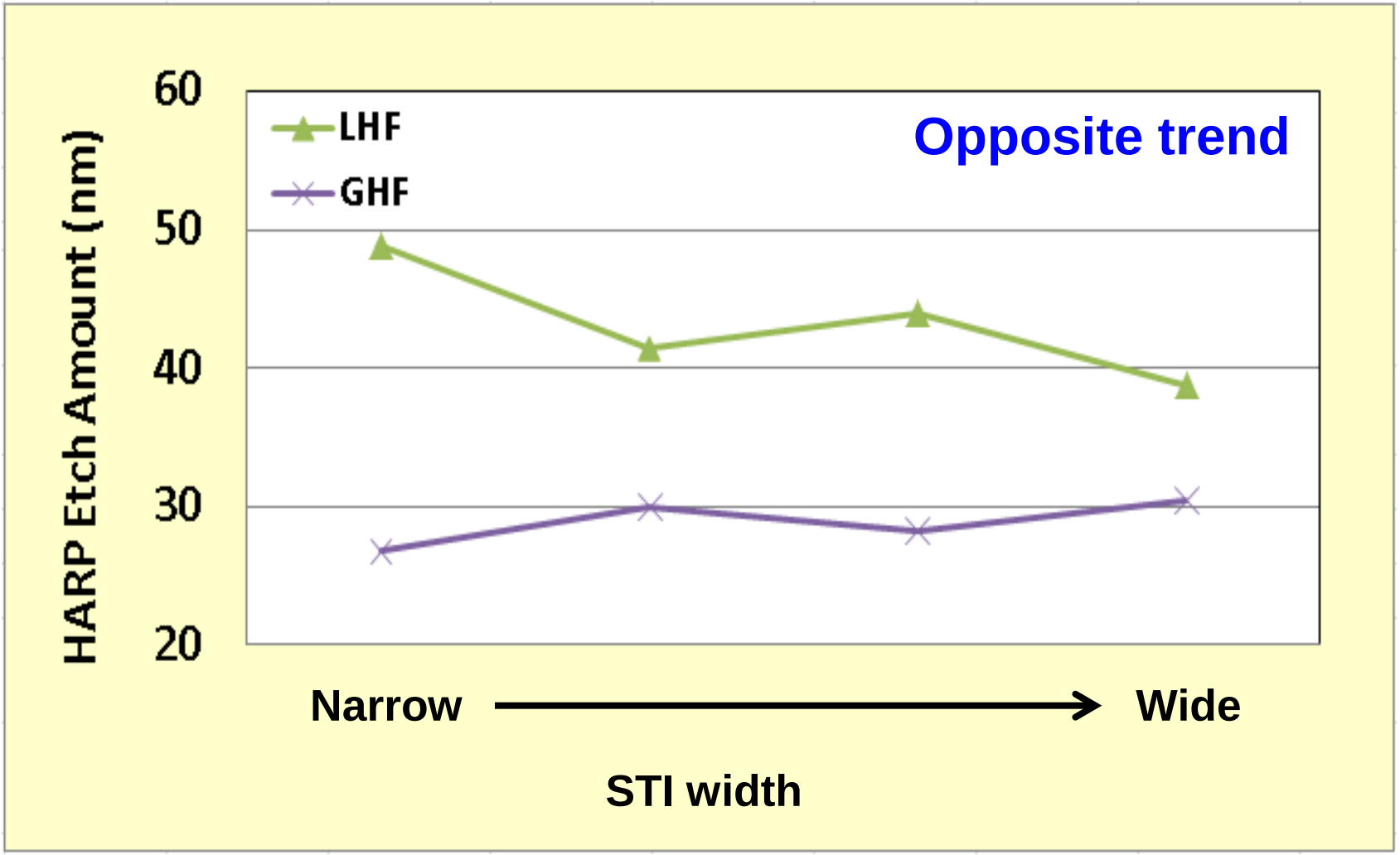
High impurity ➔ E/R slow



Less impurity ➔ E/R fast

Powerchip GHF & LHF E/A Performance Comparison

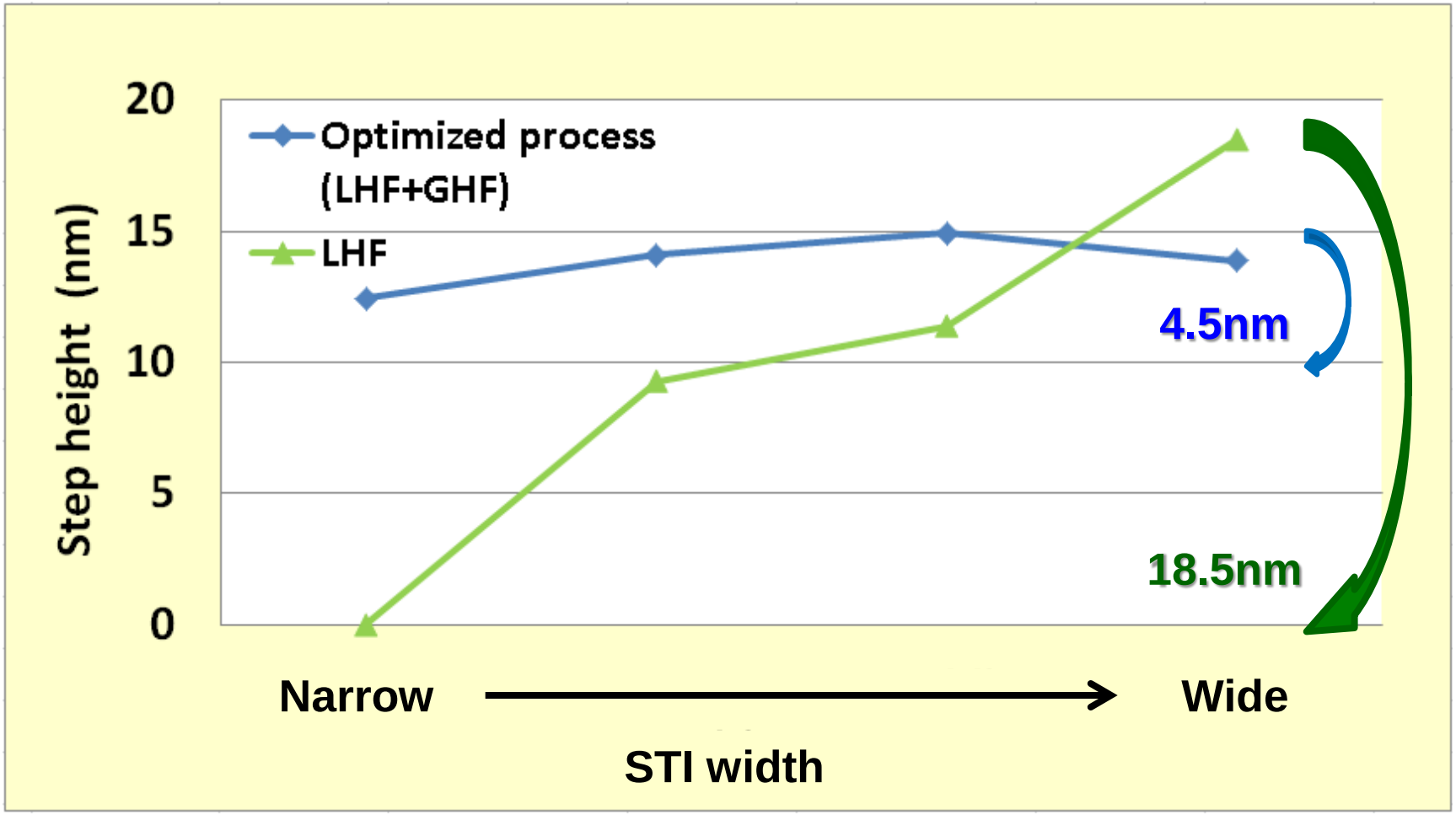
❖ LHF and GHF E/R in different STI width is opposite.

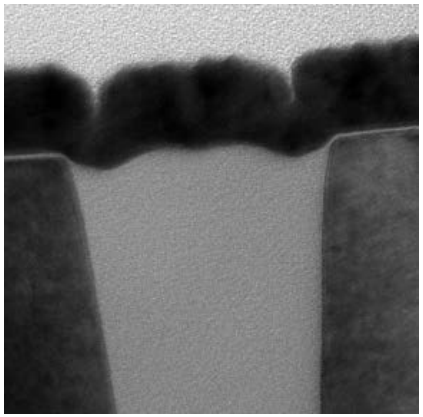
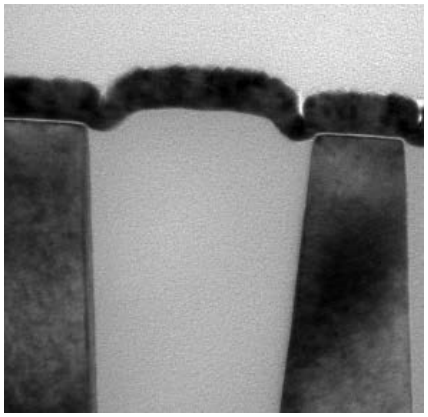
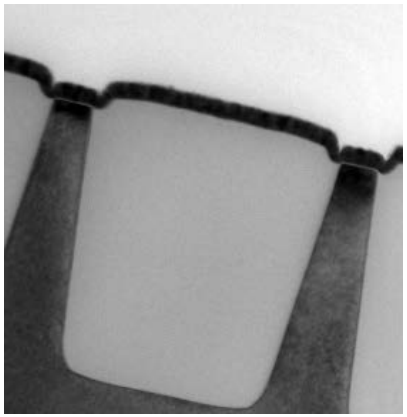
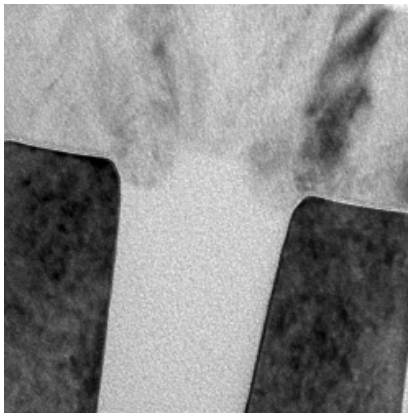
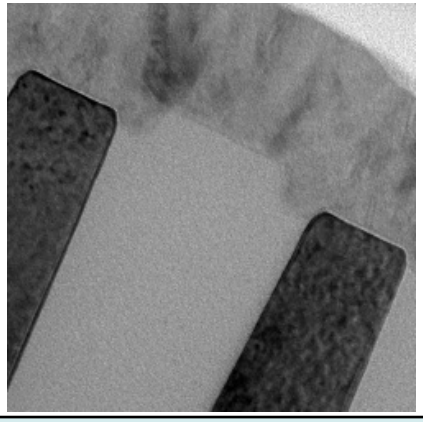
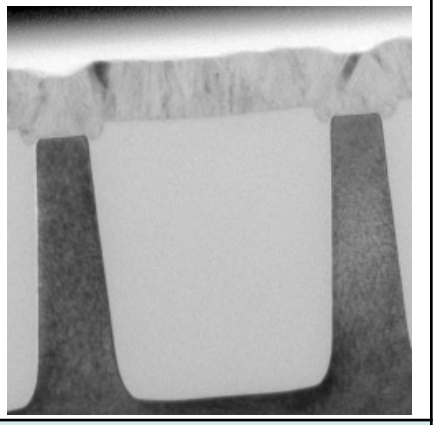


Process Optimization Result

❖ After optimizing the process flow by combining LHF and GHF, S/H bias through all STI width can be reduced from 18.2nm to 4.5nm

❖ The approach is very helpful for process window enlargement in following gate etch step.



TEM Profile			
STI width	**Narrow**	**Middle**	**Wide**
LHF only			
Step height (nm)	**0**	**11.4**	**18.5**
Optimized process (LHF + GHF)			
Step height (nm)	**12.4**	**14.1**	**14.9**

Conclusion

- The cross-linking and impurity content of annealed HARP is different between STI width, which is key impact factors of STI wet etching uniformity.

- E/R of LHF is related to oxide film hardness, on the other hand, E/R of GHF is limited by HARP impurity. Therefore, different HARP quality between STI width leads opposite E/A trend in LHF and GHF.

- Low S/H bias (<5nm) can be achieved by combining LHF and GHF, and poly gate etch process window can be enlarged by this fine-tuned STI profile.

Thank you for your attention