WET CLEAN CHALLENGES IN 22 NM ½ PITCH AND 16 NM ½ PITCH STRUCTURES

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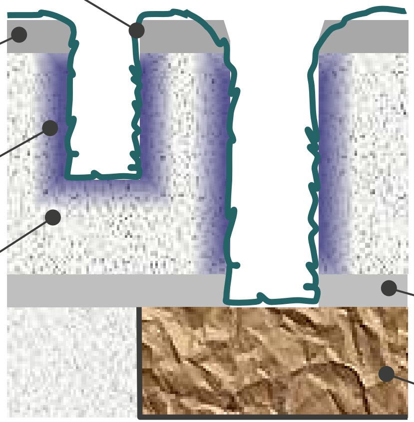
OUTLINE

- Introduction
- PERR clean for 22 nm ½ pitch structures:
  - Successful removal of fluorinated residues together with TiN HM
- Impact of dissolved oxygen in dilute HF on metal loss
  - Effect of fluid dynamics, chamber atmosphere and dissolved oxygen concentration in HF on Cu etch
- Prevention of pattern collapse by using hot IPA and SFC (surface functionalizing chemistry)
  - Parameters affecting pattern stability
  - Approaches
  - Method for surface functionalization: typical reaction
  - Impact of SFC on blanket OSG2.55, thermal oxide and 90 nm pitch high AR BEOL trench structures
  - Prevention of pattern collapse on 16 nm ½ pitch wafers after V1M2 etch using hot IPA and SFC: morphological study
- Summary

INTRODUCTION



- What is challenging regarding the PERR step?
  - Remove/ pullback or preserve TiN HM
  - Remove fluorinated polymer residues
  - Compatibility requirements:
    - Cu, Co, W, liner and barrier ➔ not to induce corrosion
      1. HF is one of the commonly used chemistries for DD clean
      2. HF based low dissolved oxygen (<20 ppb for the liquid & 500ppm (air))

    PART 1

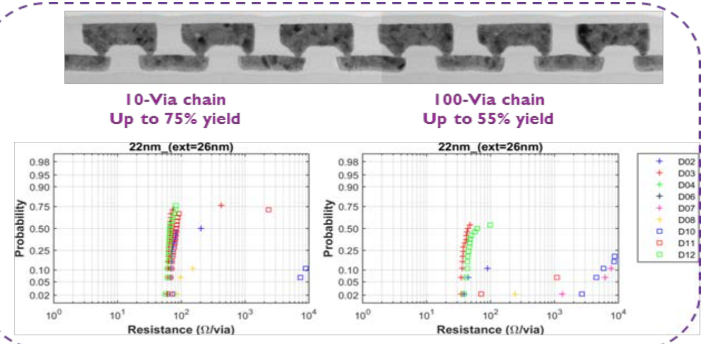
    - Advanced OSG LK (lower k-value and higher porosity), including the LK damaged layer
  - Prevention of pattern collapse
    - Transfer from 22 nm ½ pitch towards 16 nm ½ pitch, makes the structures more prone to pattern collapse

    PART 2

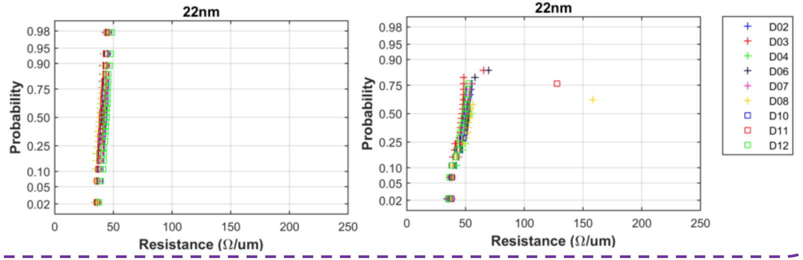
PERR CLEAN FOR 22 NM ½ PITCH STRUCTURES: SUCCESSFUL REMOVAL OF FLUORINATED RESIDUES TOGETHER WITH TIN HM

PERR CLEAN FOR 22 NM1/2 PITCH STRUCTURE

Via-litho/via-trench-etch/metallization



Keep/trench-etch/Metallization

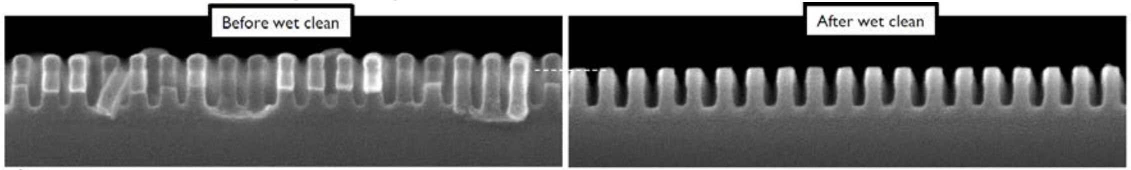


Electrical results

- **CD lines L=120um, almost 100% yield**
- **MF lines L=10400um, up to 80% yield**

POR PERR Clean (formulated chemistry - short IPA rinse dry at RT):

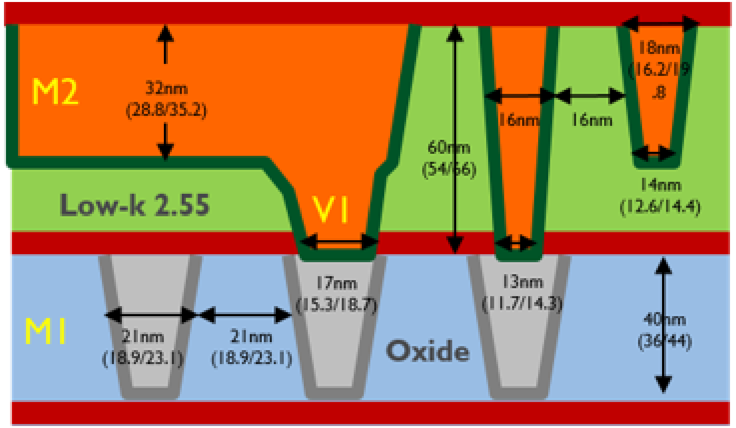
- **Removes selectively TiN together with CFx residues**

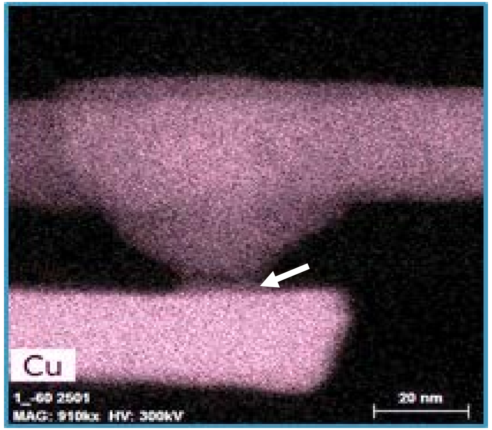


References:
E. Kesters et al., ECS Transactions, 69(8), 207-214 (2015).

IMPACT OF DISSOLVED OXYGEN IN DILUTE HF ON METAL LOSS

INTRODUCTION





- Cross-sectional representation of the two level metal structure (16 nm ½ pitch structure)
- 16nm M2 dual-damascene structures metallized with Copper

Briggs et al., to be presented at IITC, 2017.

- Clean concept transferred from 22 nm ½ pitch to 16 nm ½ pitch structures:
  - Further reduction Cu loss during cleaning sequence required
    - HF based low dissolved oxygen cleans are reported to be crucial for DD cleans

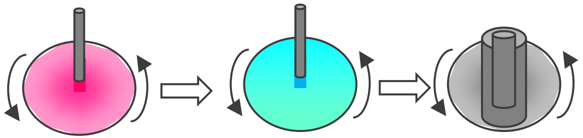
E. Kesters et al., Solid State Phenomena, 1012-0394, Vol. 255,pp. 251-254.

L. Broussous et al., Solid State Phenomena, 1012-0394, Vol. 255,pp. 260-264.

    - Rinse optimization using dNH_4OH vs. dCO_2 (not discussed)

MATERIALS AND METHODS

- SU-3200 platform, SCREEN Single wafer cleaning tool

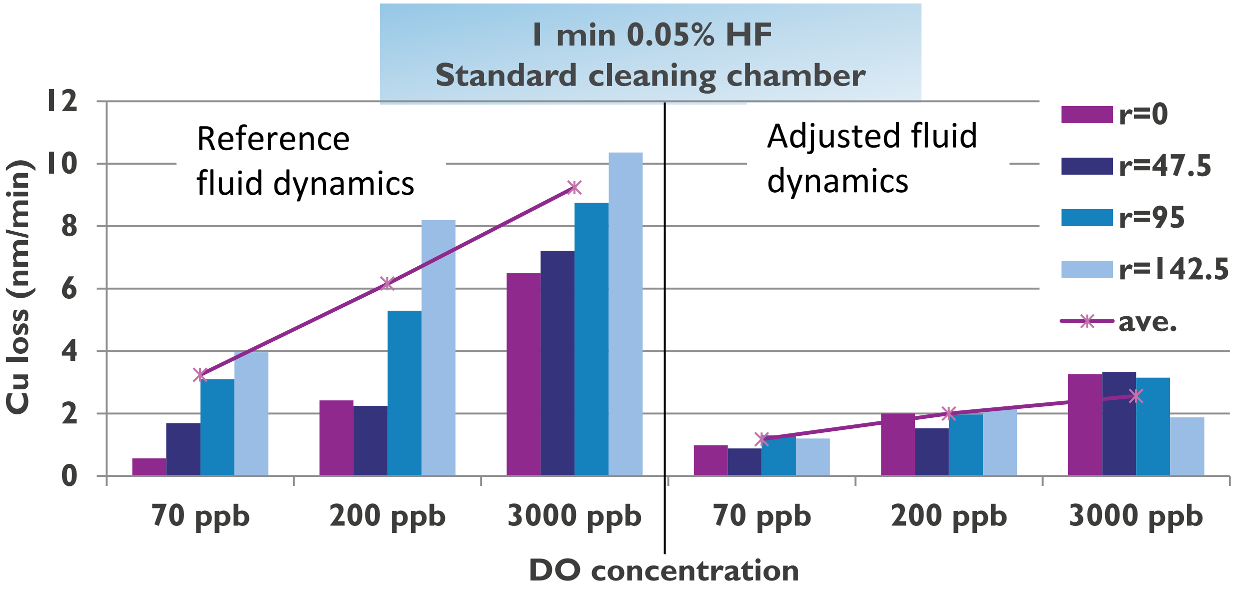


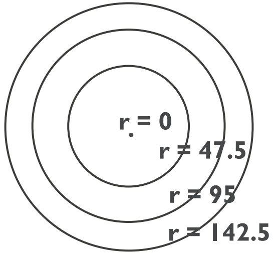
- [HF]: 0.05 – 0.1%
- DO: 70 - 3000 ppb
- Process time : 20, 60 and 120 s
- Other variables:
  - ambient oxygen (controlled vs. non-controlled)
  - fluid dynamics (reference vs. improved)

- Materials:
  - 500 nm blanket ECD Cu

- Characterization:
  - 4-point probe measurement (sheet resistance)

EFFECT OF FLUID DYNAMICS ON CU ETCH



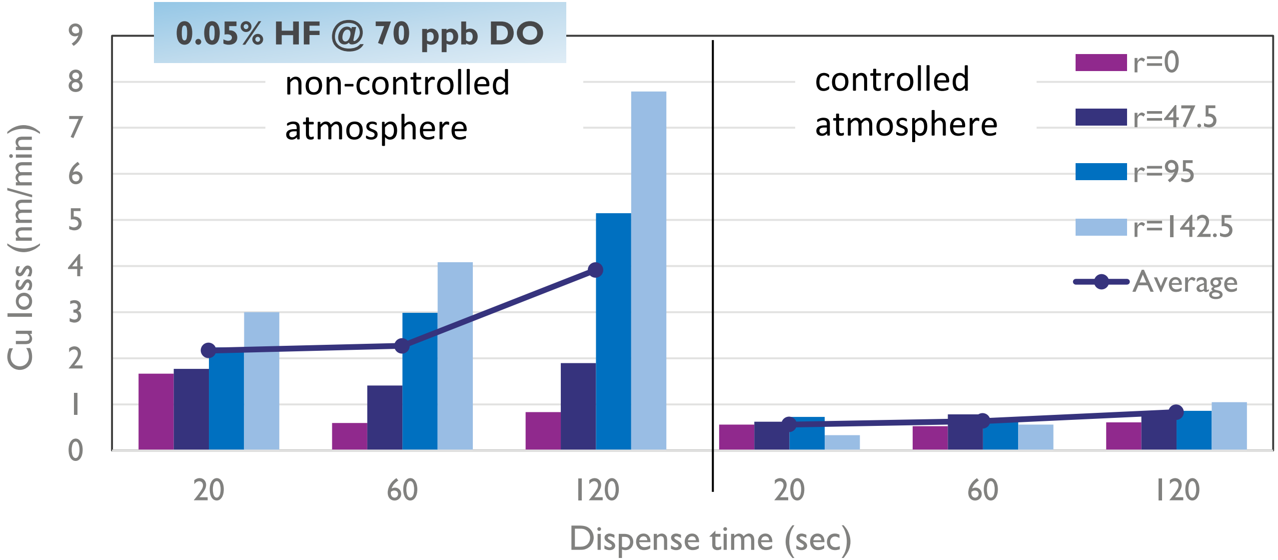


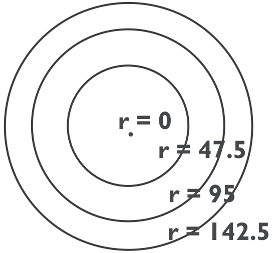
- Copper loss increases with increased DO concentration in dHF solution (70 to 3000 ppb DO)
- Improved fluid dynamics reduces the amount of Cu loss

  → prevents copper losses towards wafer edge are suppressed, even at increased DO (= 3000 ppb)

If you are not able to control the ambient atmosphere, fluid dynamics can improve the metal compatibility when using dHF

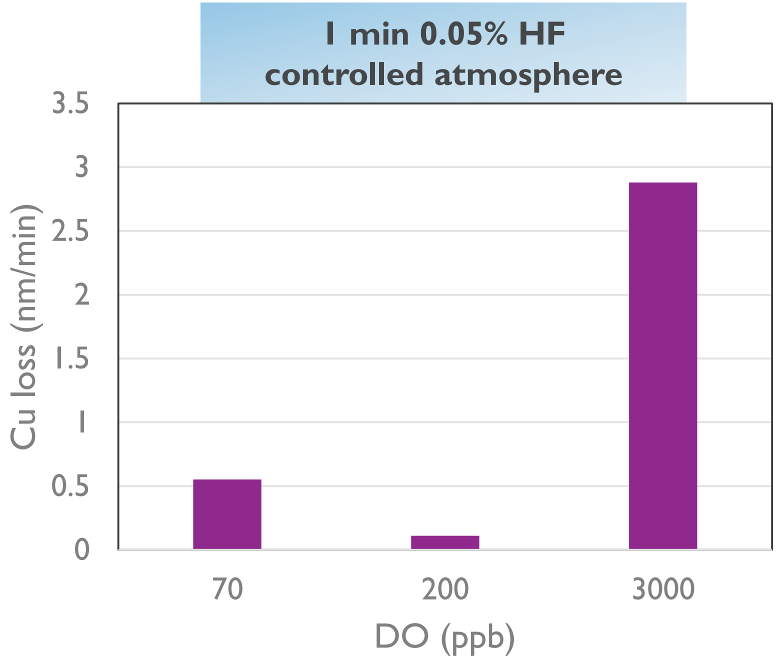
EFFECT OF CHAMBER ATMOSPHERE ON CU ETCH





- Non-controlled ambient combined with low DO 0.05% HF process:
  - It was observed that the Cu etch was higher toward the outer peripheral side of the wafer compared to the controlled ambient.
  - Cu loss increased with dispense time.
- Controlled ambient (low oxygen ambient) combined with low DO 0.05% HF:
  - did not attack bulk Cu, even after 2 min dispense

EFFECT OF DISSOLVED OXYGEN CONCENTRATION IN DHF SOLUTION ON CU ETCH



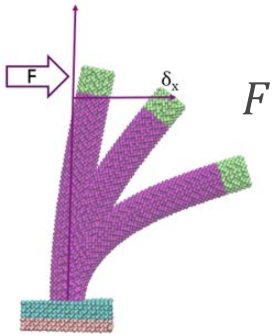
- Cu loss increased with increasing DO concentration in dHF
- Cu loss with 0.05% HF:
  - ≤ 200 ppb DO: less than 1 nm Cu loss was observed
  - 3000 ppb DO: Cu loss > 1 nm
- A similar trend in etching behavior was observed using 0.1 and 0.2% HF (not shown)

The etching behavior of Cu strongly depended on:

- DO concentration and was not affected by the HF concentration (0.1 – 0.2% range).
- If HF is used for PERR (in combination with formulated chemistries) , be aware that DO concentration is low enough

PREVENTION OF PATTERN COLLAPSE BY USING HOT IPA AND SFC (SURFACE FUNCTIONALIZING CHEMISTRY)

PARAMETERS AFFECTING PATTERN STABILITY

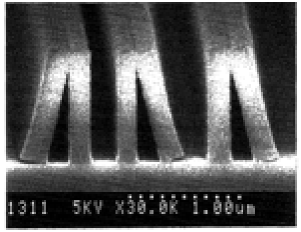


$$F \propto \frac{EI}{h^3}\delta_x \sim \frac{E\,w\,s}{AR^3}$$

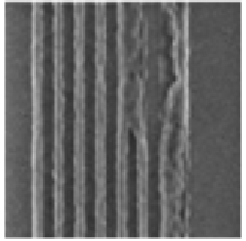
- E: Young's modulus
- AR: aspect ratio
- w: width in transvers direction
- s: space between nearby structures
- Surface chemistry of the dielectric sidewall
- Wet clean chemistry and rinse liquid

Non-rigid materials, collapse at low AR

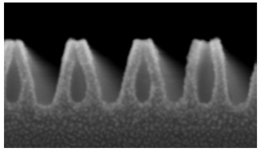
Resist: 150 nm L/S, AR~ 6, *Tanaka, 1993, Jpn. J. Appl. Phys,*



EUV resist: 28/32 nm L/S, AR ~ 2.8, *Yoshimoto, 2011, SPIE*

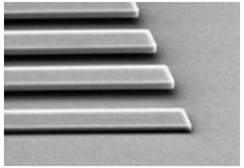


Low k: 45 nm L/S, AR~ 5

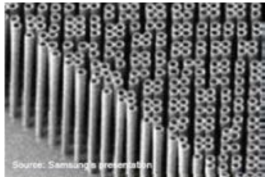


Rigid materials, collapse at high AR

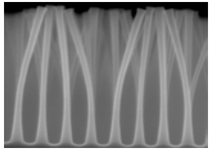
MEMS AR~20-100



DRAM capacitors

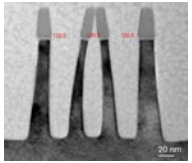


Si pillars AR~ 20



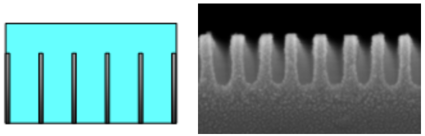
Rigid materials, moderate AR

Si fins AR<10



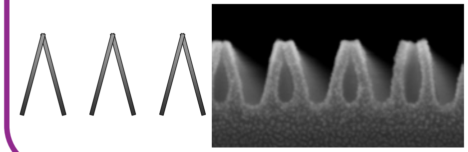
PREVENTION OF PATTERN COLLAPSE: APPROACHES

No bending when fully immersed → Capillary force causes bending → Stiction held by surface adhesion



$$F_{capillary} \geq F_{elastic}$$

$$F_{adhesion} \sim F_{elastic}$$



X. Xu et al., ACS Nano 8(1), 885-893 (2014)

M. Sankarapandian et al., Solid State Phenom. 195, 107 (2013)

- Capillary force induces bending
  ➔ reduce capillary force such that

1. During spin-rinse drying by an IPA final rinse at elevated temperatures
   → Low surface tension liquid: e.g. IPA drying, max 3x reduction in force
   - Water: γ= 0.072 N/m
   - IPA: γ= 0.021 N/m

2. Capillary force can be reduced further by changing the surface energy of low-k lines.
   - This can be done by modification of the structures surface wetting properties by deposition of an organic monolayer providing a contact angle of 90 deg or above

- Reduce collapse force: Modify exposed surface without damaging the low-k

imec

METHOD FOR SURFACE FUNCTIONALIZATION: TYPICAL REACTION

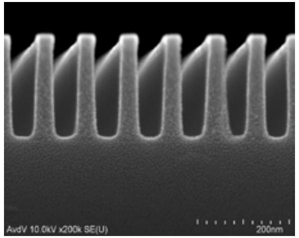
- Restoration of damaged layer is performed by a silane-coupling reaction using organic solvent
- Silylation process
  - Success criteria: reactivity of surface (sidewall and bulk - pore wall), solubility of silylating agents in solvent
  - Limited at the surface of the damaged low-k if silylating molecule size > pore diameter
  - Incorporation of silylating molecules in low-k bulk if silylating molecule size < pore diameter
- *Use of surface functionalizing agents as part of the rinsing sequence*

IMPACT OF SFC ON
BLANKET OSG2.55, THERMAL OXIDE AND
90 NM PITCH HIGH AR BEOL TRENCH STRUCTURES

SURFACE FUNCTIONALIZATION: EXPERIMENTAL

Test materials

- Blanket OSG 2.55 and thermal oxide
- 45 nm ½ pitch low-k stack, AR ~6.5



- 16 nm ½ pitch structures after V1M2 etch

Surface functionalization

- SCF chemistry
- Room temperature
- Immersion time:
  - 0 – 60s

Rinse & Dry

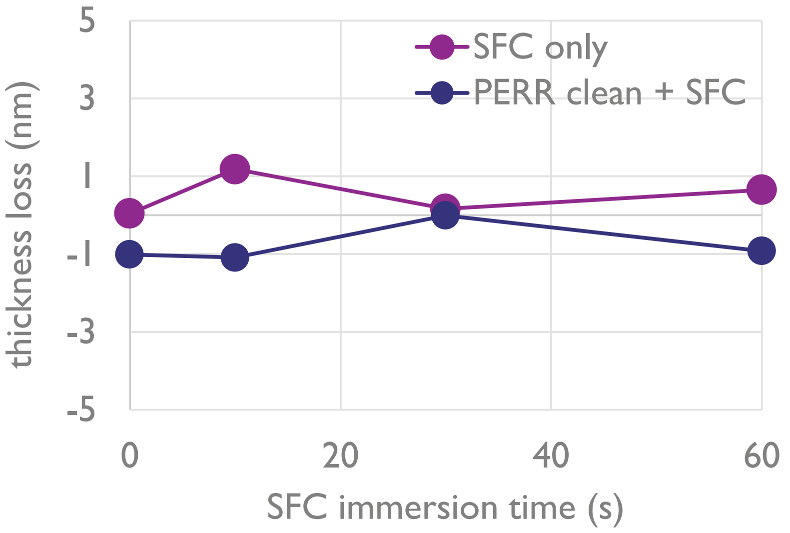
- IPA/ 2 min/ RT

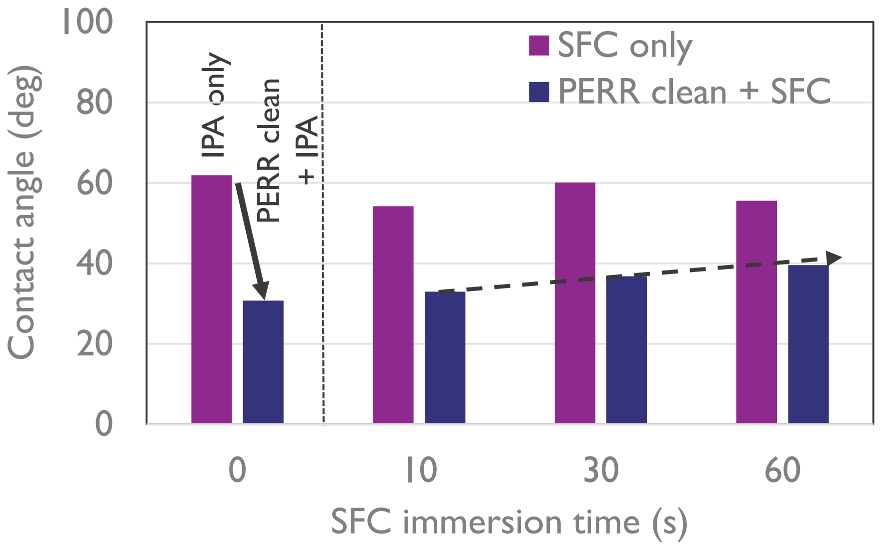
- Contact angle (reference)
- Spectroscopic Ellipsometry (Reference sample)

- Contact angle (treated samples)
- Spectroscopic Ellipsometry (treated samples)

RESULTS

PLASMA-TREATED OSG 2.55



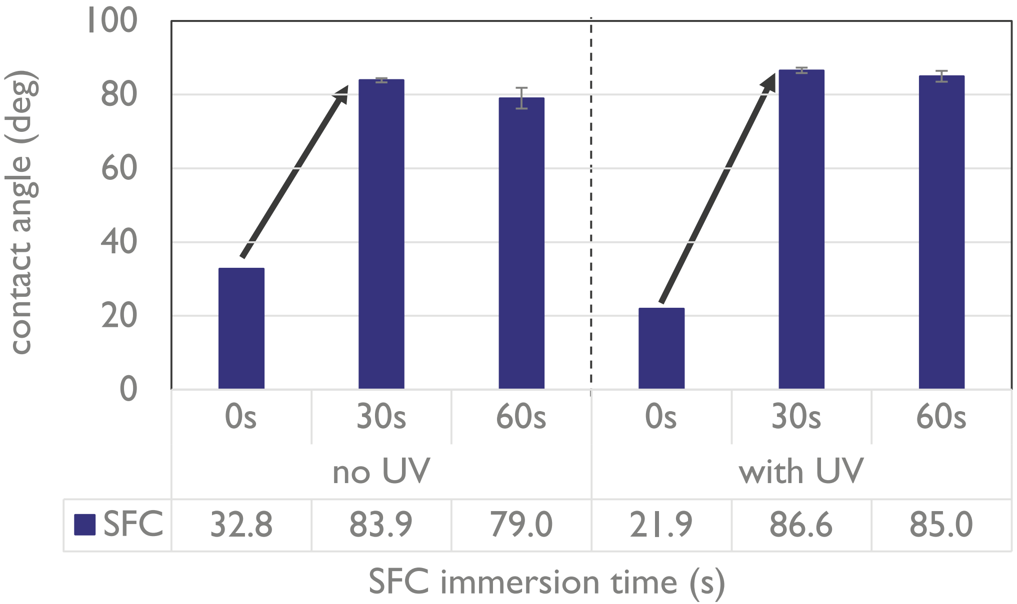


- Negligible change in thickness because of PERR clean
- PERR clean induces a decrease in contact angle of ~ 30 deg
- Thickness remains similar after SFC immersion, while contact angle is slightly increasing with SFC immersion time

SFC shows a limited reaction with plasma-treated OSG 2.55 surface

RESULTS

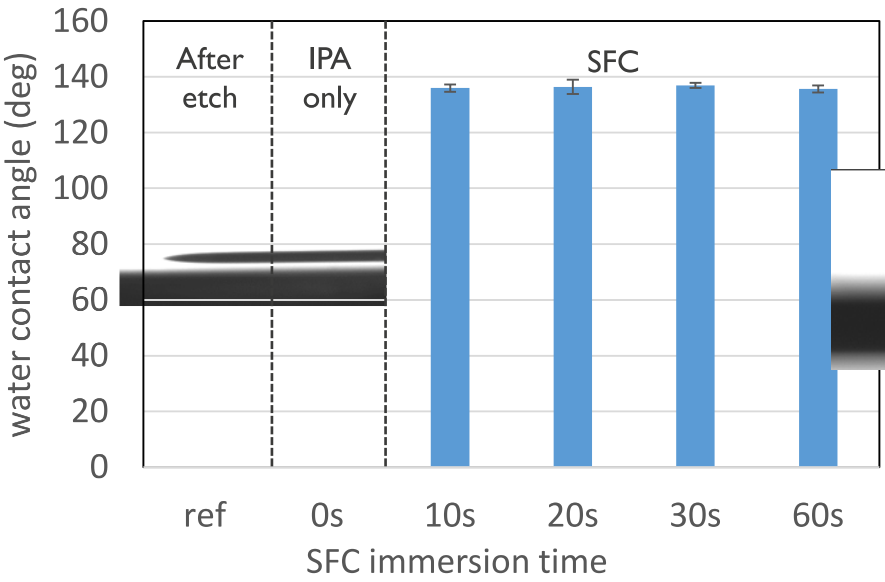
THERMAL OXIDE

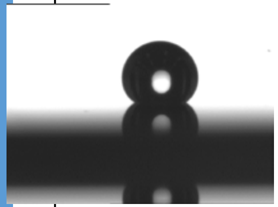


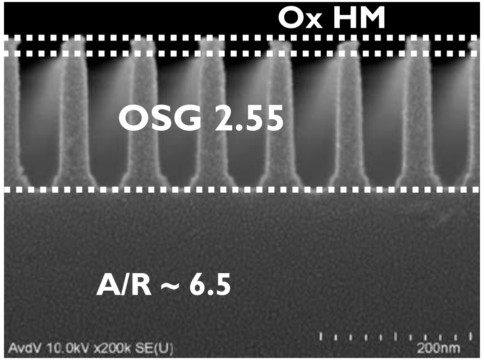
- Thermal oxide surface is hydrophilic before SFC treatment
- UV/O_2 pre-treatment in order to condition the surface (to increase [OH] on surface)
- Contact angle substantially increase to ~ 90 deg independent from immersion time and surface pre-conditioning
- Without UV pre-conditioning: good surface to start reaction of SFC

SFC: Reactivity thermal oxide >>plasma-treated OSG 2.55

CONTACT ANGLE HIGH A/R 90 NM PITCH BEOL TRENCH STRUCTURE







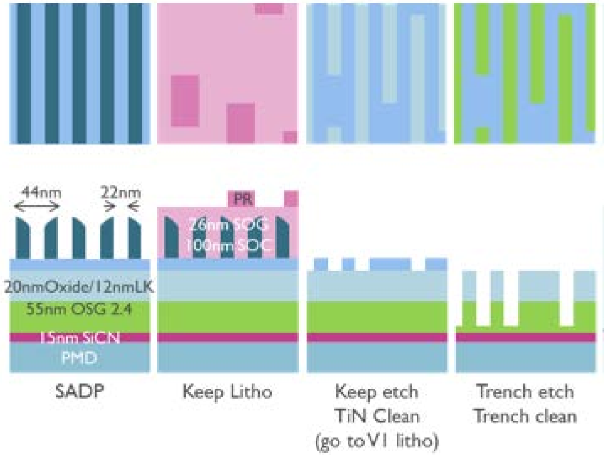
- Large change in contact angle (> 100deg) after treatment for10 s in SFC
- SFC present at the surface
- Functionalizing oxide HM is successful

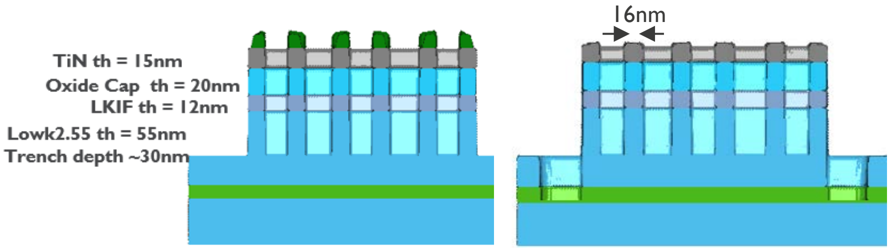
Functionalization of the top surface plays a key role to prevent lines from pattern collapse

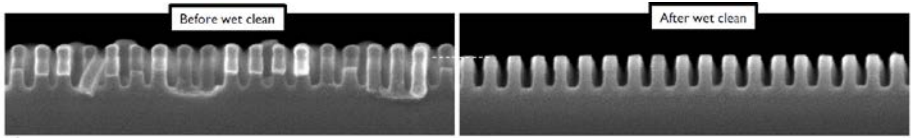
PREVENTION OF PATTERN COLLAPSE ON 16 NM ½ PITCH WAFERS AFTER V1M2 ETCH USING HOT IPA AND SFC: MORPHOLOGICAL STUDY

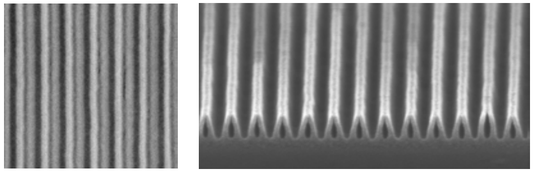
TRANSFER FROM 22 NM ½ PITCH TOWARDS 16 NM ½ PITCH STRUCTURES

22 nm ½ pitch structure	16 nm ½ pitch structure





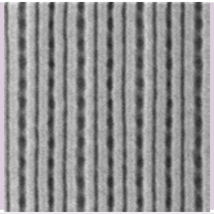
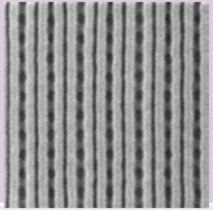
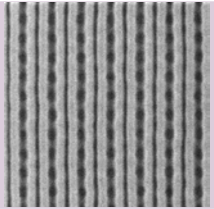
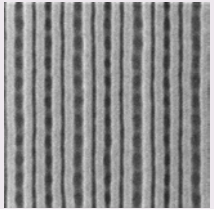
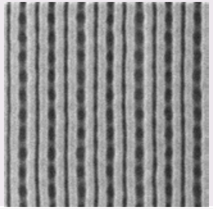
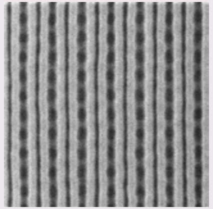
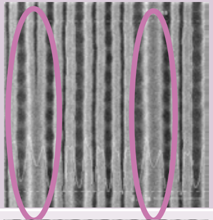
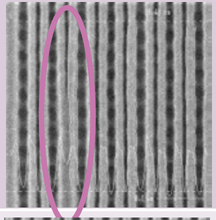
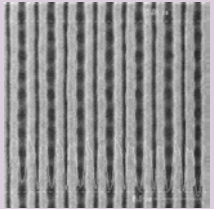
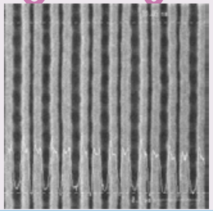
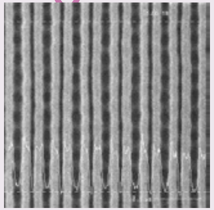
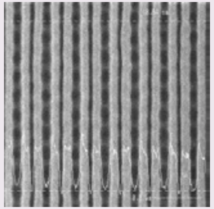




Transfer from 22 nm ½ pitch towards 16 nm ½ pitch:
→ structures are more prone to collapse after POR PERR clean (formulated chemistry + short IPA rinse at RT)

EFFECT OF HF TIME

[HF] = 0.05% IPA = 120s

HF	PERR	RINSE - DRY	CD (nm)	(0,0)	(0,3)	(0,5)	remark
0s	120s	IPA (65C)	19.8				No collapse seen without HF pre treatment
10s	120s	IPA (65C)	19.1				Reducing HF time from 20s to 10s helps to prevent lines to collapse
20s	120s	IPA (65C)	18.5				Collapse observed Difference in line CD of ~1.3nm between the 0s and the 20s dHF
20s	120s	SFC + IPA (RT) SFC + IPA (65C)	18.5				Adding SFC prevents lines to collapse even with 20s dHF Even rinsing using IPA at RT, no collapse was observed

A threshold w.r.t. CD has been observed and SFC has a positive impact on pattern collapse reduction

SUMMARY

1. Impact of dissolved oxygen in dilute HF on metal etch
   1. Tuned fluid dynamics reduces copper losses towards wafer edge, even at increased DO (= 3000 ppb) concentrations
   2. The Cu loss was also strongly dependent on the chamber atmosphere condition.
   3. The etching behavior of Cu strongly depended on the DO concentration and was not affected by the HF concentration (within 0.1 – 0.2 % range).

1. Pattern collapse prevention
   1. Functionalization of the top surface plays a key role to prevent lines from pattern collapse
   2. How to prevent line collapse for 16 nm ½ pitch structures?
      1. Increase IPA rinse from RT to 65C
      2. CD control: A threshold w.r.t. CD is observed for pattern collapse
      3. Make use of SFC in rinse-dry sequence:
         1. Adding SFC step prevents the lines to collapse, even with 20s 0.05%HF pre-treatment and IPA RT

ACKNOWLEDGEMENT

SCREEN

Akihisa Iwasaki

embracing a better life