# The Effect of Ash Processes on Inorganic Porous Low-k Materials

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## Outline

- Background/Motivation
- Effects of Downstream Ash
- Effects of In-Situ RIE Ash
- Evaluation of New Ash Chemistries
- SLM (Single Layer Metal) Integration
- Conclusions



## Why the Need for Low-k

It's all about speed

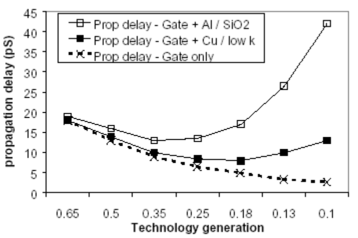


Figure 1: Dependence of propagation delay on technology node

As transistor size shrinks, the interconnect dominates propagation delays



## Low-k Materials Choices

| Deposition Process | Candidate Materials | k value | Vendor |
|---|---|---|---|
| CVD | Black Diamond™ | < 3.0 | Applied Materials |
| | Coral® | 2.5-3 | Novellus |
| | Aurora™ | 2.0-2.7 | ASMI |
| | Orion™ | 2.0-2.5 | Trikon |
| Spin-On | LKD 5109 | 2.2 | JSR |
| | HOSP™ | 2.5 | Honeywell |
| | NANOGLASS® | 1.5-2.6 | Honeywell |
| | *SiLK** | *2.1-2.6* | *Dow Chemical* |
| | *GX-3™* | *1.9-2.7* | *Honeywell* |
| | Zircon™ | 1.9-2.7 | Shipley |

Carbon based materials

Si-C-OH Materials

Preservation of Porosity and Composition of Si-C-OH Materials Dictate Process Window

SiLK is a trademark of the Dow Chemical Company
Coral is a registered trademark of Novellus
Zircon is a trademark of Shipley Company
Aurora is a trademark of ASMI
Orion is a trademark of Trikon
Black Diamond is a trademark of Applied Materials



## Low-k Materials Integration Challenges

**Patterning**
- Photo resist poisoning
- Etch profile control
- Ash damage (Surface limiting or Bulk)
- Wet clean compatibility

**Metallization**
- CTE mismatch between Cu and Low-k materials
- Step coverage / Side wall roughness

**CMP**
- Adhesion of Low-k materials
- CMP delamination



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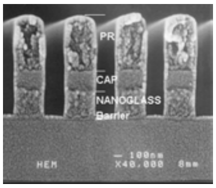
## Effects of Conventional Downstream Ash - Dimension

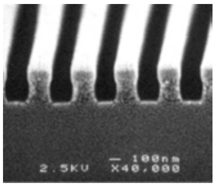
Pre-Ash




Downstream $O_2$ Ash

1100W, 1200mT, 2000sccm $O_2$, 250°C

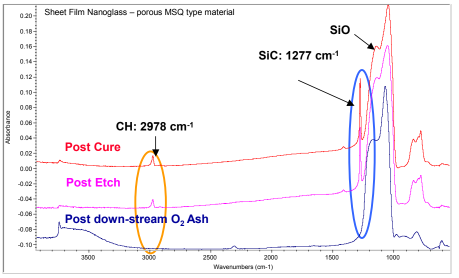
Post Downstream-Ash



Side-wall bowing was observed after conventional downstream $O_2$ ashing



## Effect of Conventional Downstream Ash - Composition




All organic species are lost after conventional downstream ash process as indicated by the disappearance of SiC and CH peaks in FTIR spectra



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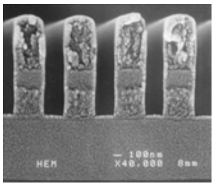
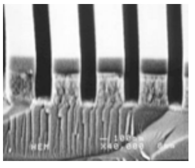
## In-situ RIE Ash - Dimension

Pre-Ash

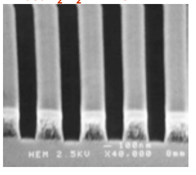


In-situ RIE Ash

Post $O_2$ RIE Ash



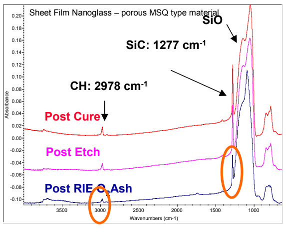
Post $N_2/H_2$ RIE Ash

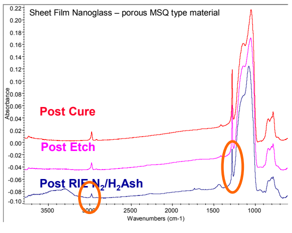


Use of an in-situ RIE ash preserves CD



## Effect of Etch & In-situ Ash - Composition



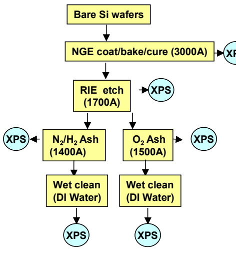




| | SiC/SiO | Chg% SiC/SiO |
|---|---|---|
| Post Cure | 0.0303 | |
| Post etch | 0.0267 | -11.71 |
| Post Etch+$O_2$ Ash | 0.0155 | -48.80 |
| Post Etch+$N_2/H_2$ Ash | 0.0183 | -39.17 |

Significant carbon depletion in the bulk is measured after etch and ash processes



## Effect of Etch & In-situ Ash on Surface Carbon Depletion




- Etch results in 30% carbon depletion @ surface
- Etch+Ash results in 80% carbon depletion @ surface

### Effect of Oxidative Ash

| | %C ((C-C,H) |
|---|---|
| Control | 16.1 |
| Etch | 11.9 |
| Etch/$O_2$ ash | 2.7 |
| Etch/$O_2$ ash/DI | 2.7 |

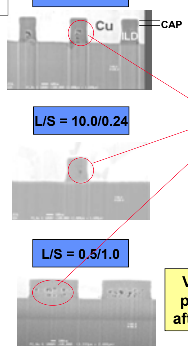
### Effect of Reductive Ash

| | %C ((C-C,H) |
|---|---|
| Control | 16.1 |
| Etch | 11.9 |
| Etch/$N_2$-$H_2$ ash | 2.6 |
| Etch/$N_2$-$H_2$ ash/DI | 3.3 |

## Consequence of C-depletion in Porous SiCOH Materials

**Process Flow:**

- $SiO_2$\SiN\NANOGLASS®E\$SiO_2$
- Trench litho
- Etch ($C_4F_8$/CO/Ar/$N_2$)
- Ash ($O_2$)
- PVD Barrier Seed TaN/Ta/Cu
- ECP Cu
- Pre CMP Anneal 200°C/60min
- FIB




Voids are observed in porous dielectric layer after pre-CMP Cu anneal



## Possible Mechanism

| MOST LIKELY SUSPECTS | MECHANISM | |
|---|---|---|
| Trench etch | Carbon depletion | Material is now structurally altered |
| Ash | | |
| Wet clean | May interact with Ash | |
| Degas/Barrier dep/Cu seed dep | No direct impact (Can affect Stress in annealed Cu) | |
| Cu electroplating (15000A) | No direct impact (Can affect Stress in annealed Cu) | |
| Anneal (200C, 60 min) | Stress | TENSILE Stress pulls material apart. |

**Major factors in porous in-organic dielectric voiding:**

C-depletion, Stress



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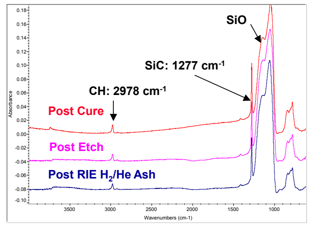
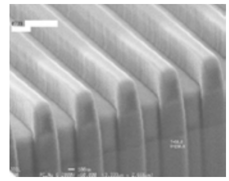
## A New Ash Process - $H_2$/He

$H_2$-He ash (300°C, 120s) – Process run by Axcelis Technologies



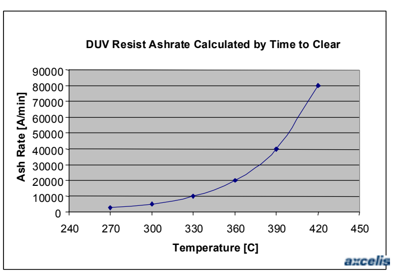



| | Chg% SiC/SiO |
|---|---|
| Post Cure | |
| Post etch | -12.84% |
| Post etch + ash | -17.44% |

- $H_2$/He ash can effectively remove resist with little carbon depletion in porous Low-k materials
- Carbon depletion during ash may depend on the carbon depletion during etch. A modification of the etch recipe could help to further reduce carbon depletion during both etch and ash

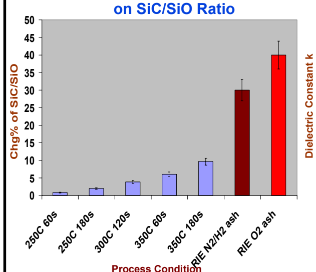


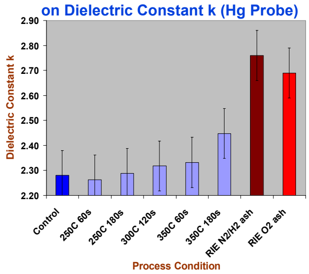
## DUV Resist ash rate






## Process Optimization of $H_2$/He Ash




- $H_2$/He ash is less destructive than Std. Ash
- Selection of process conditions (ash temp/time) depends on resist removal rate and minimal damage to Low-k material

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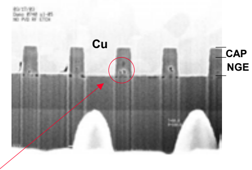
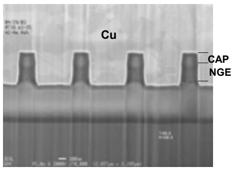
## SEM Images of SLM Structures

Control ( RIE $O_2$ ash)



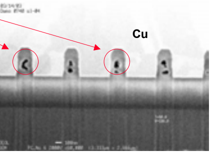

$H_2$-He ash(350°C, 210s)

$H_2$/He plasma ash




Voiding

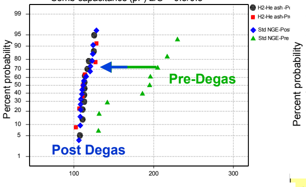
Control ( RIE $N_2$ / $H_2$ ash)

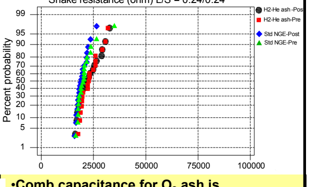


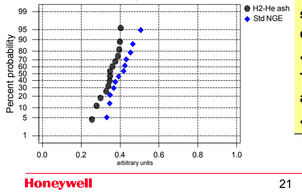

Voids in porous Low-k materials can be significantly reduced by using $H_2$/He plasma strip instead of in-situ RIE ash



## SLM Electrical Test Data




- Comb capacitance for $O_2$ ash is significantly higher than $H_2$/He ash before degas
- Post degas capacitance is similar for both. This indicates significantly lower moisture absorption in the case of $H_2$/He ash
- RC product is similar for the two conditions



## Summary

- Conventional down stream $O_2$ ash results in both dimensional change (bowed profile) and compositional change (carbon depletion) in porous Si-C-OH dielectrics
- In-situ RIE ash does not affect etch profile, but results in significant carbon depletion(40-50%) which will lead to voiding in porous Si-C-OH dielectrics
- Modified $H_2$/He ash process can minimize carbon depletion and therefore significantly reduce voiding in porous Low-k materials
- Electrical data indicates usage of $H_2$/He ash results in improved dielectric performance (capacitance) to conventional ash processes



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