Repairing Process-Induced Damage to Porous Low-k ILDs by Post-Ash Treatment

Anil Bhanap, Teresa Ramos, Anna Camarena and Ananth Naman

Honeywell Electronic Materials, 1349 Moffett Park Dr, Sunnyvale, CA 94089

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Brian Daniels, Paul Apen

Outline

- Background/Problem statement
- Hypothesis/Proposed solution
- Experimental
- Results
  - Blanket films characterization
  - SLM structures characterization
- Conclusions

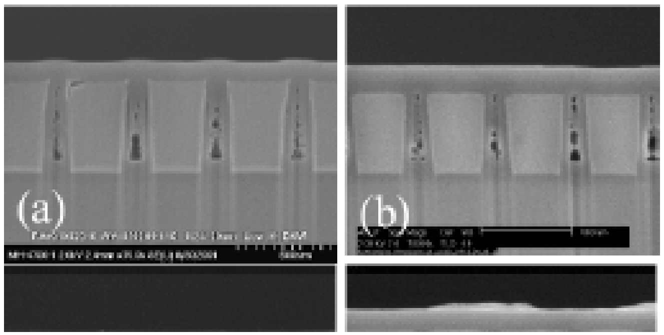
Introduction

Challenges in integration of porous inorganic low-k dielectrics in Cu DD processing

- Adhesion (CMP compatibility)
- Sensitivity to plasma damage ←
- CD/Profile control
- Barrier integrity
- K stability

Motivation

Porous Low-k materials are prone to void formation during Cu damascene processing



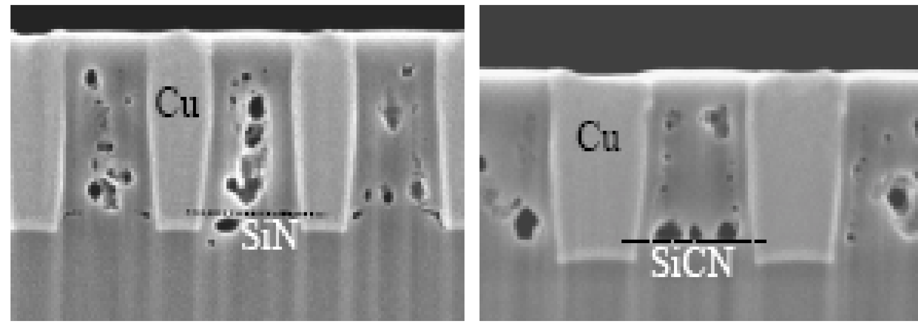


Figure 2: Voiding in MSQ film

<u>Reference</u>

CVD Barriers for Cu with Nanoporous Ultra Low-k: Integration and Reliability

J. C. Lin[1,2], R. Augur[1,3] S. L. Shue[2], C. H. Yu[2], M. S. Liang[2], A. Vijayendran[4], T. Suwwan de Felipe[4] and M. Danek[4].
[1] International Sematech, Austin, TX, USA;
[2] Taiwan Semiconductor Manufacturing Company, Taiwan, R.O.C.
[3] Philips Semiconductor, The Netherlands;
[4] Novellus Systems, San Jose, CA.
E-mail: jclinb@tsmc.com.tw

<u>Proceedings of the International Interconnect Technology Conference, 2002, 21 (2002)</u>

<u>Reference</u>

Voiding in Ultra Porous Low-k Materials
Proposed Mechanism, Detection and Possible Solutions

Thieu Jacobs[1,2)], Ken Brennan[1,3)], Ron Carpio[1)], Karsten Mosig[1,4)], Jing-Cheng Lin[1,5)], Henri Cox[1,2)], Walt Mlynko[6)], Jo Fourcher[1)], Joe Bennett[1)], Josh Wolf[1,7)], Rod Augur[1,2)] and Paul Gillespie[1,3)]

[1]International SEMATECH, 2706 Montopolis Drive, Austin TX 78741; [2]Philips Semiconductors, Eindhoven, Netherlands;
[3]Texas Instruments, Dallas, TX, USA; [4]Infineon Technologies, München, Germany; [5]TSMC, HsinChu, Taiwan; [6]IBM, Burlington, VT, USA; [7]Intel, Portland, OR, USA

Hypothesis

PROCESS STEPS → **POTENTIAL EFFECTS**

PROCESS STEPS	POTENTIAL EFFECTS
Trench etch	Carbon depletion, Fluorine Contamination
Ash	Carbon depletion
Wet clean	Depends on previous processing
Degas/Barrier dep/Cu seed dep	No direct impact (Can affect Stress in annealed Cu)
Cu electroplating	No direct impact (Can affect Stress in annealed Cu)
Anneal	Tensile Stress

Carbon depletion, Fluorine Contamination / Carbon depletion → **Low-k material composition is altered**

Tensile Stress → **TENSILE Stress causes structural changes leading to void formation**

<u>Main factors in porous inorganic Low-k voiding are:</u>

A) Carbon depletion
B) Tensile Stress

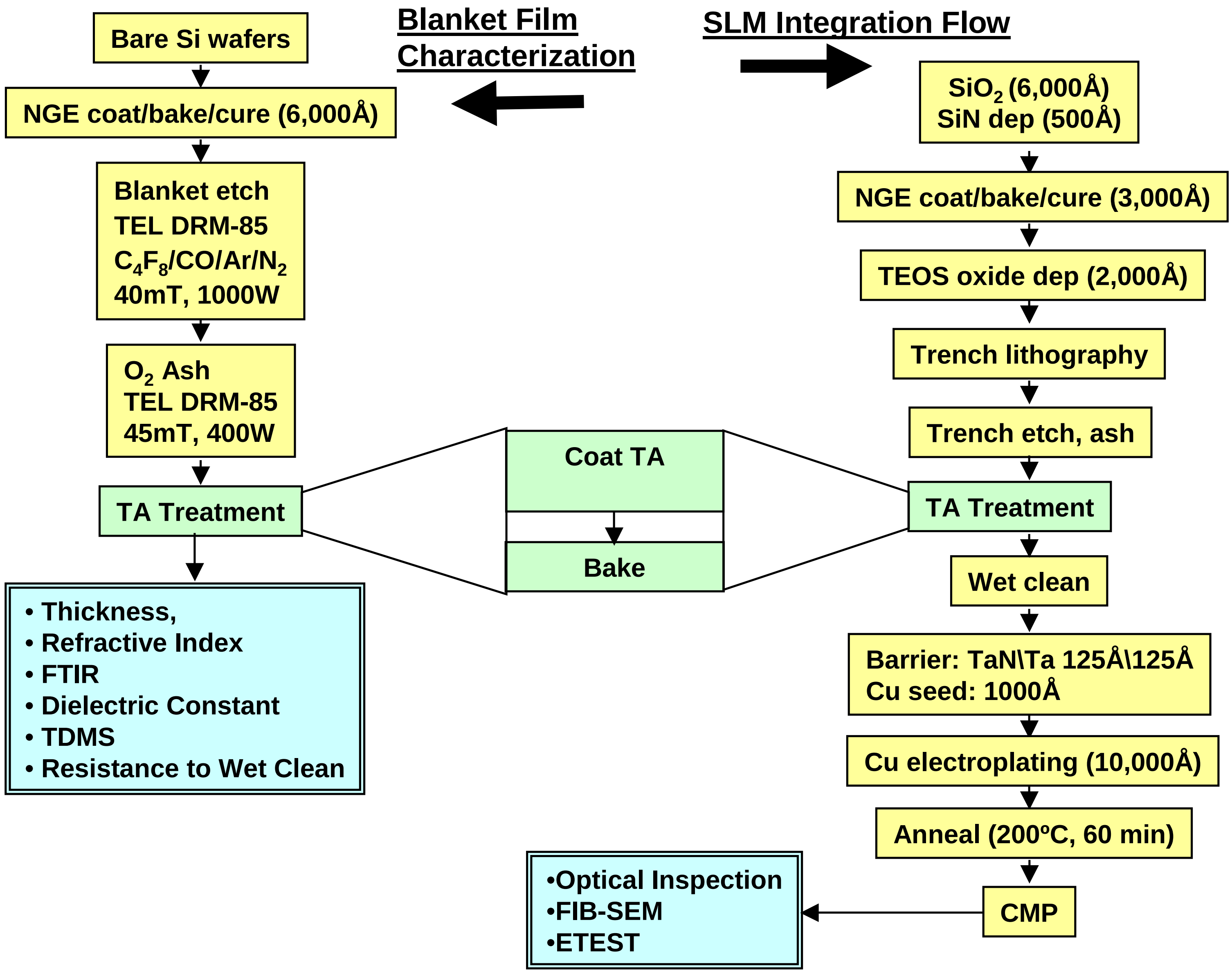
Paths Investigated

Approach	Benefits	Issues
Reduce C-depletion using a non-damaging ash. e.g. H_2/He	Eliminates primary cause of C-depletion	Does not address C-depletion during other process steps
Replenish carbon through post-ash treatment	Repairs all prior damage Well established etch-ash processes can be used	Volatile emission

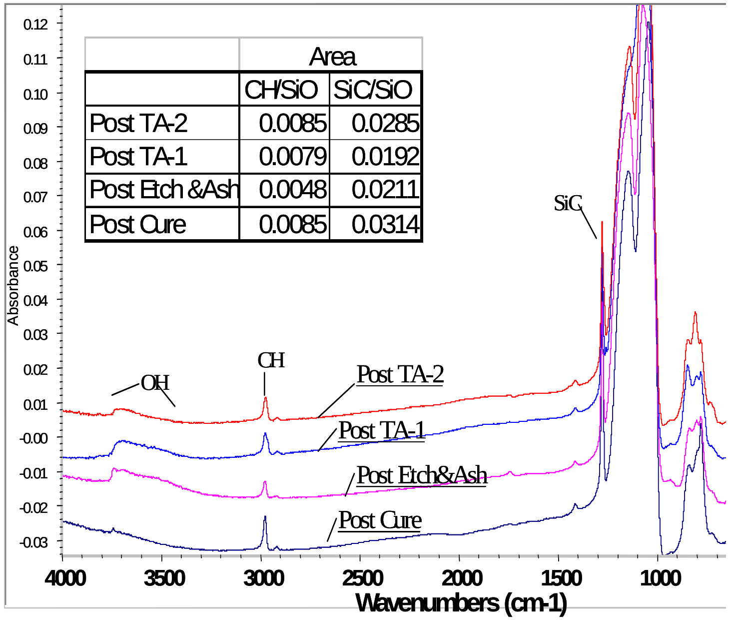
<u>Toughening Agent</u>
(TA)

Optimize
TA material/ process

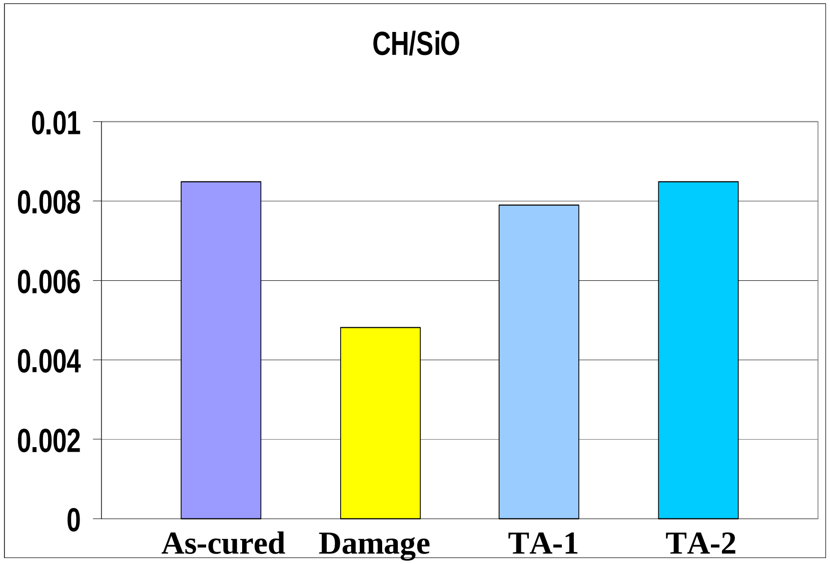
Experimental Set-Up



Restoration of Carbon

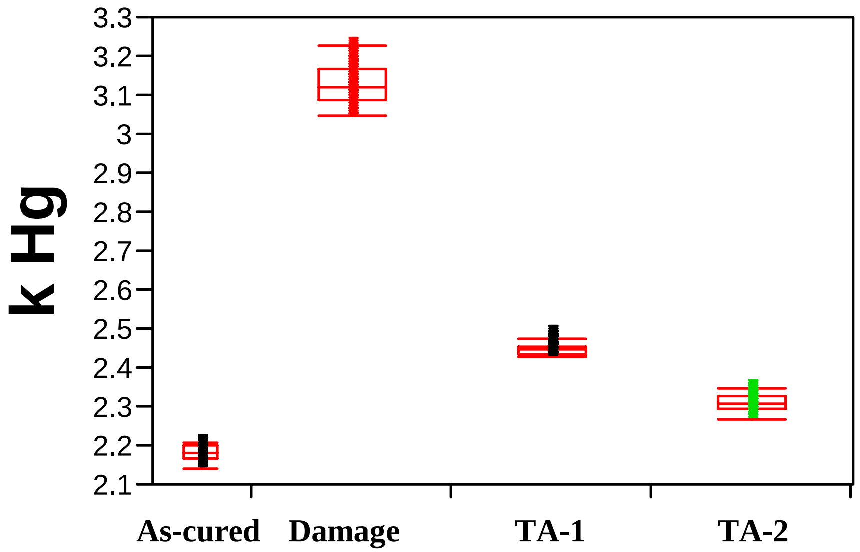


	Area	
	CH/SiO	SiC/SiO
Post TA-2	0.0085	0.0285
Post TA-1	0.0079	0.0192
Post Etch &Ash	0.0048	0.0211
Post Cure	0.0085	0.0314



- Plasma damage (etch and ash) lead to significant reduction in carbon content (CH/SiO).
- TA-1 and TA-2 treatments replenish carbon to near post-cure level

Restoration of dielectric constant

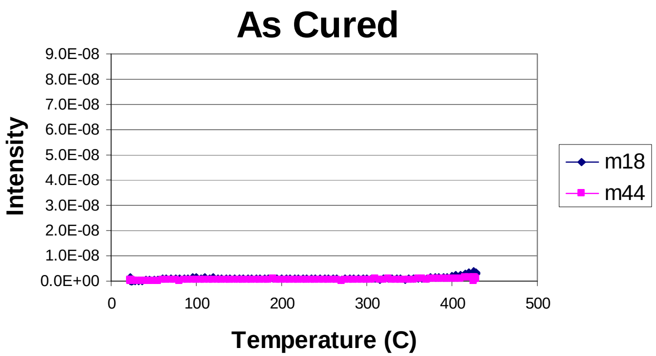


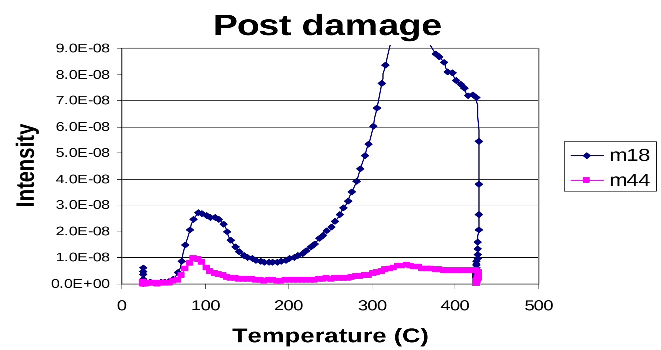
- Reduction in carbon content (due to etch and ash) results in increased dielectric constant relative to post-cure k value

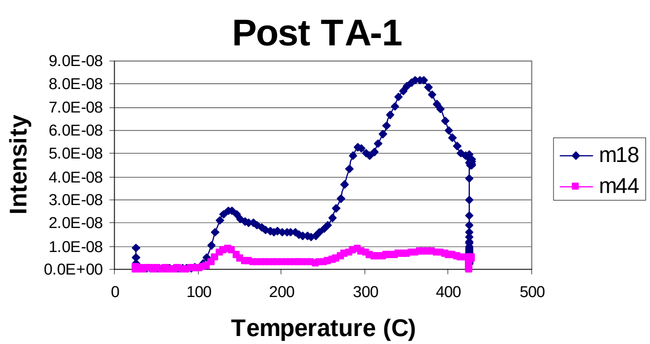
- Carbon replenishment by TA-1 and TA-2 treatments leads to restoration of dielectric constant to near post-cure level

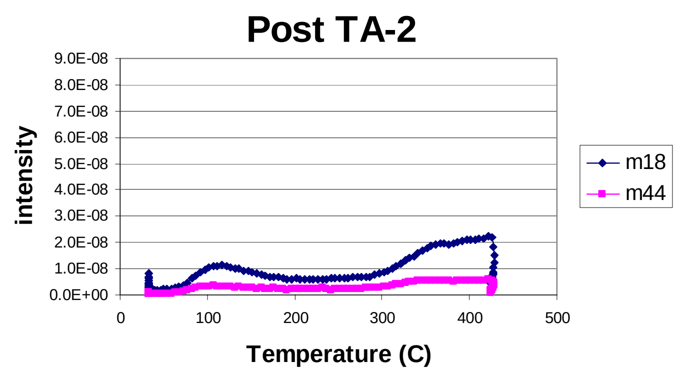
Reduced Outgassing with TA-2

TDMS on NANOGLASS®E Films at various process steps









- Etch and Ash of NANOGLASS®E Films results in increased outgassing

- TA-2 treatment is effective in significantly reducing outgassing, whereas TA-1 treatment does not reduce outgassing

Toughening Agent Enables Wet Clean

Effect of exposure to various wet clean chemistries on NANOGLASS®E films after etch-ash (control) and after etch-ash and TA-1 treatment (TA-1)

Wet Clean condition	**Etch rate (Å/min)**		**DI water contact angle (degree)**	
	Control	**TA-1**	**Control**	**TA-1**
No wet clean			<10	122
A (Dilute HF)	>1000	0	33	112
B (Aqueous acidic)	5	0	< 10	118
C (Semi-aqueous fluoride)	25	14	< 10	< 10
D (Organoamine)	70	23	< 10	47

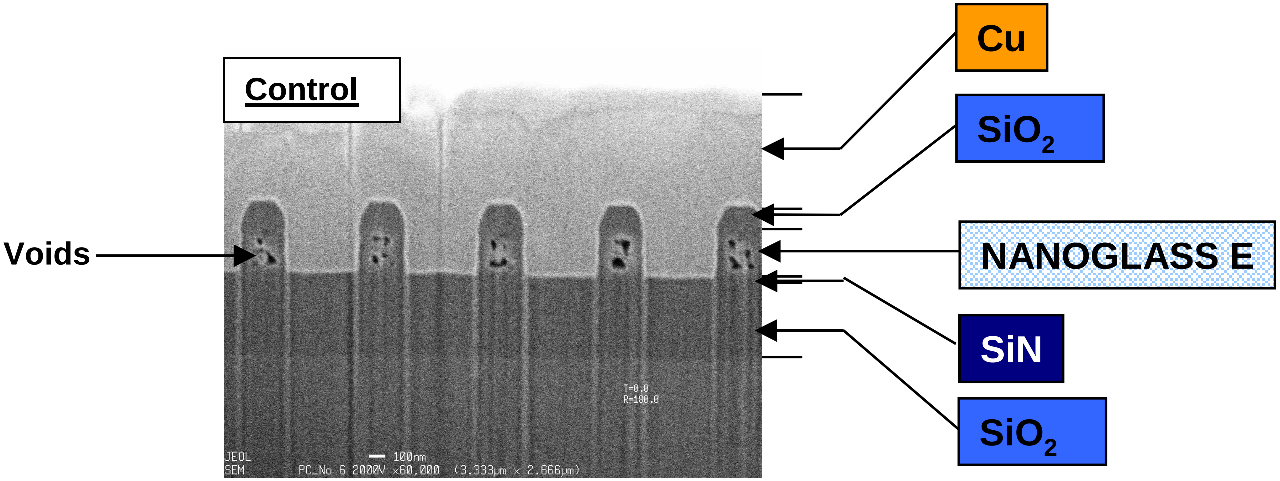
- NANOGLASS E becomes hydrophilic after etch and ash, and has high etch rate in most wet clean chemistries
- TA treatment restores hydrophobicity, and improves resistance to wet clean chemistries

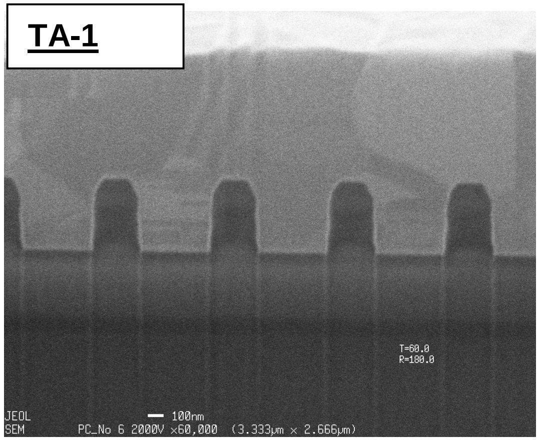
Blanket Film Summary

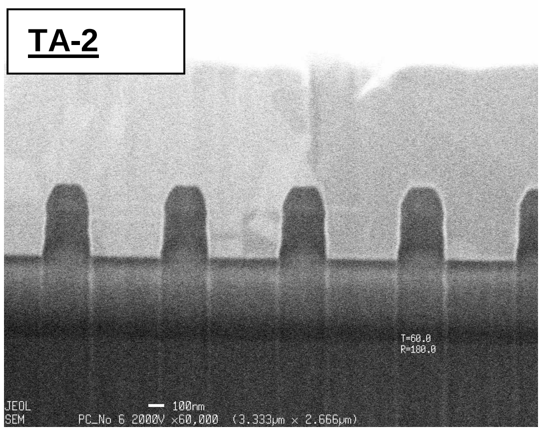
Properties	Method	As Cured NANOGLASS®E Films (425°C/ 60 min)	Post Etch and Ash NANOGLASS®E Films	Post TA Treated NANOGLASS®E Films	
				TA-1	TA-2
Carbon Content	FTIR CH/SiO ratio	0.0085	0.0048	0.0079	0.0085
Dielectric Constant	Hg Probe	2.20	3.10	2.45	2.35
Leakage Current (A/cm^2) @ 2 MV/cm	Hg Probe	2.73E-8	2.14E-4	1.88E-7	1.72E-8
Hydrophobicity	Contact Angle	65	<10	122	118

Elimination of Voids in ILD

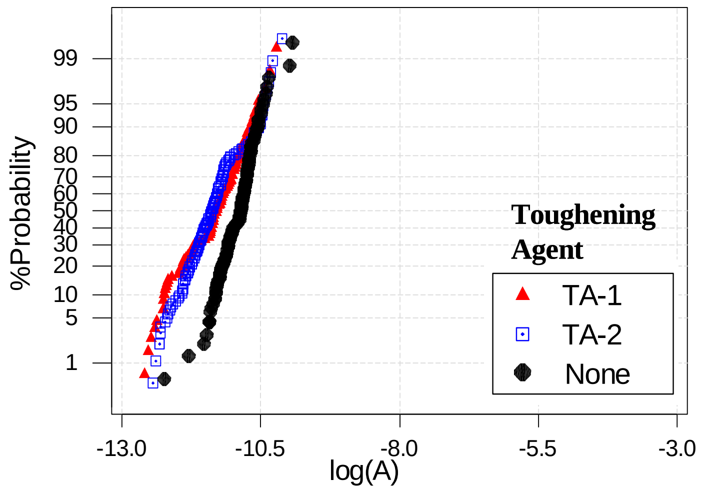
FIB-SEM micrograph after Cu annealing



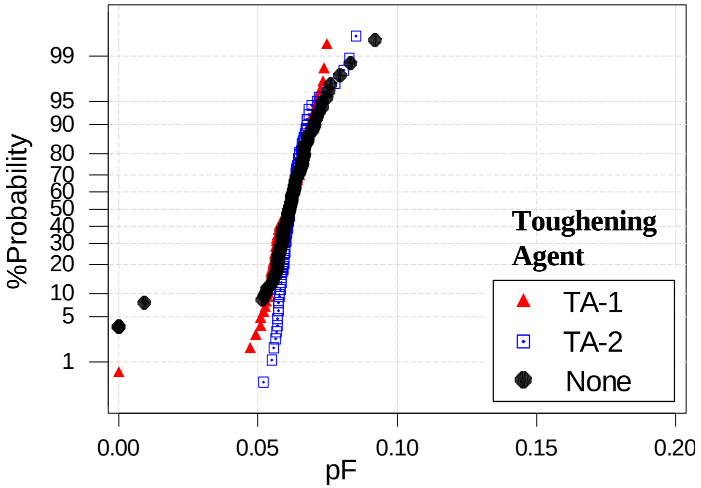




Both Toughening Agents are effective in preventing void formation



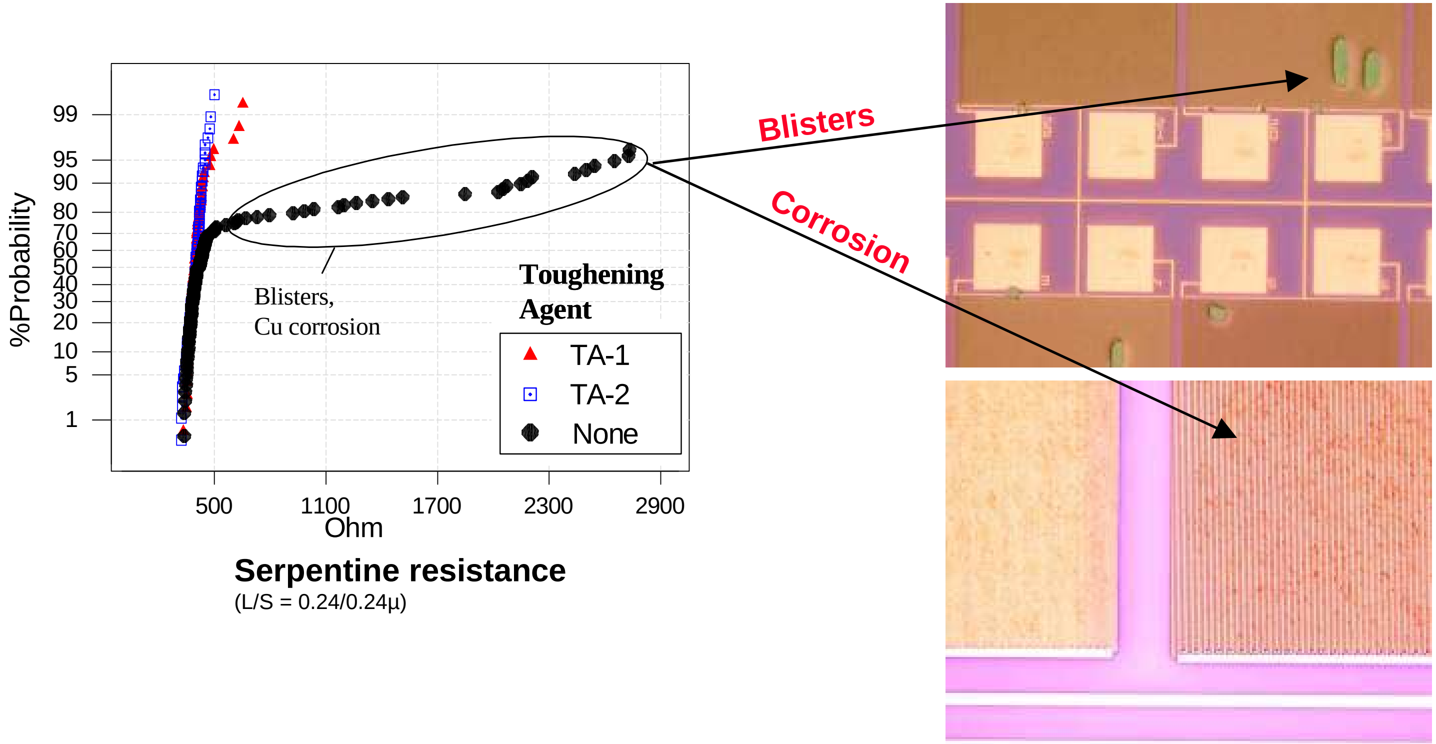
Leakage current
(L/S = 0.24/0.24µ)



Comb capacitance
(L/S = 0.5/0.24µ)

- Use of either TA treatment slightly reduces line-to-line leakage current
- TA treatment does not change median capacitance, but results in higher comb capacitance yield, due to fewer defects

Benefits of Hydrophobicity



Serpentine resistance
(L/S = 0.24/0.24μ)

- Residual moisture in un-treated NANOGLASS causes blisters, Cu corrosion and pitting, leading to wide serpentine resistance distribution.
- Wafers treated with either TA-1 or TA-2 does not show such defects, and has tight resistance distribution

Conclusions

- A post-ash treatment with Toughening Agents TA-1 or TA-2 restores the properties of NANOGLASS®E to its original state
- TA treatment eliminates voids in NANOGLASS®E SLM interconnect structures
- By increasing chemical and structural stability of the porous Low-k ILD, TA treatment can improve the process window (wet clean compatibility), SLM interconnect yield, and Cu reliability
- TA treatment may be applicable to other SiCOH based Low-k materials, enabling their application in the high volume production of advanced Cu interconnects