Cleaning of Photoresist and Etch Residue from Dielectrics using Supercritical CO_2

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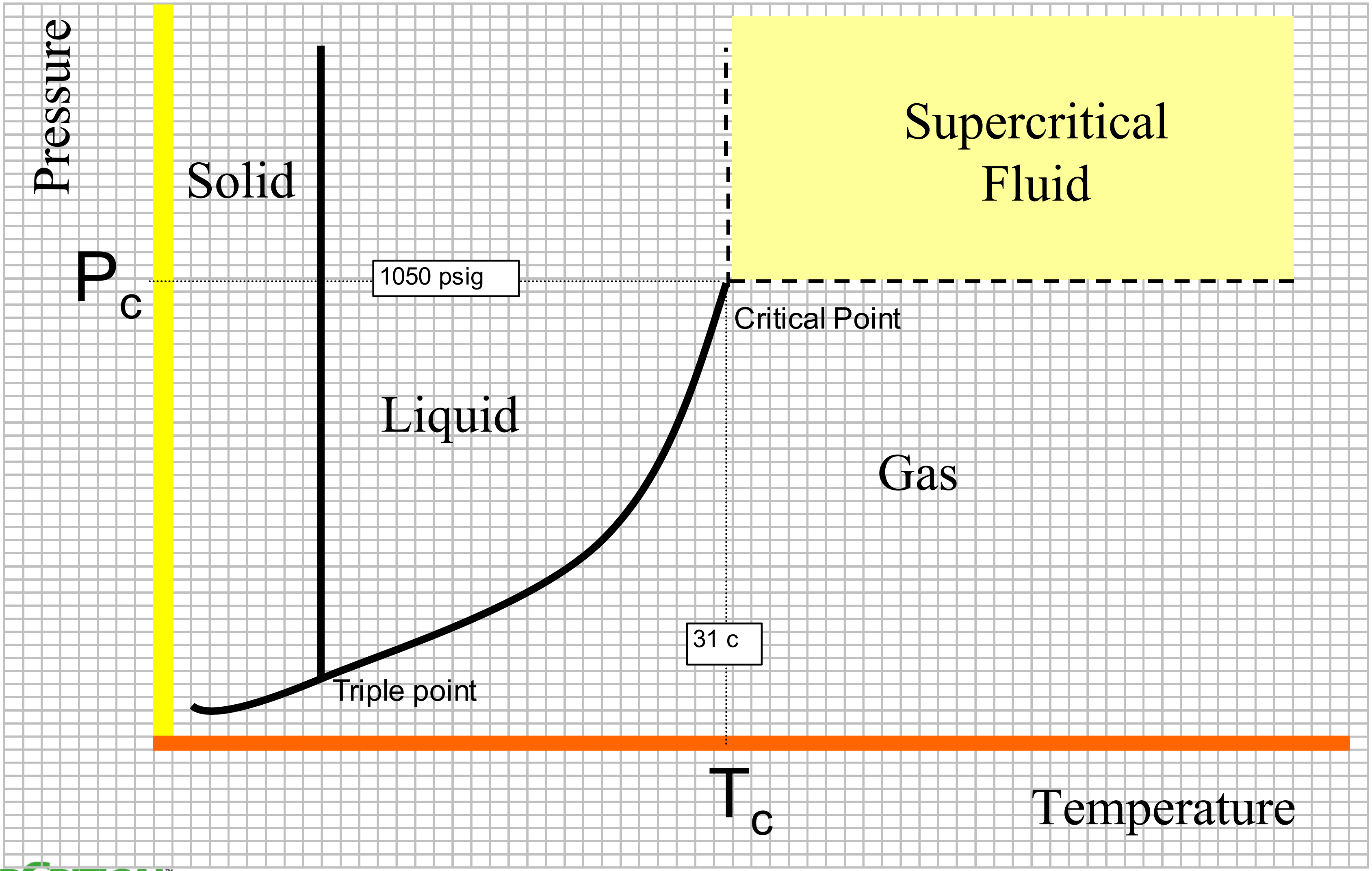
Outline

- Introduction
  - Supercritical Fluids
  - Industrial Applications
- Process Flows
- Hardware and Process Conditions
- Results
- Tools and CO_2 Supply
- Summary

P/T Phase Diagram



Critical Parameters

Fluid	T_c (°C)	P_c (bar)
Xe	17	58
CO_2	31	73
C_3H_8	97	42
NH_3	132	113
MeOH	239	81
H_2O	374	220

Carbon Dioxide

- Non-toxic, Non-flammable
- Compatible with existing HP equipment
- Inexpensive
- Environmentally friendly

Solvent	Viscosity	Surface Tension	Density
Liquid CO_2	0.08	1.5	0.87[3]
SC-CO_2	0.03[2]	**≈ 0**	0.3[2]-0.8
H_2O	1.00	72	1.0

[1]at 20º C and 105 atm
[2]at 35º C and 75 atm

Industrial Applications

- Supercritical Fluid Chromatography
- Supercritical Fluid Extraction
- Synthesis of polymers and pharmaceuticals
- Particle formation
- Degreasing of machined parts
- Dry cleaning of clothing

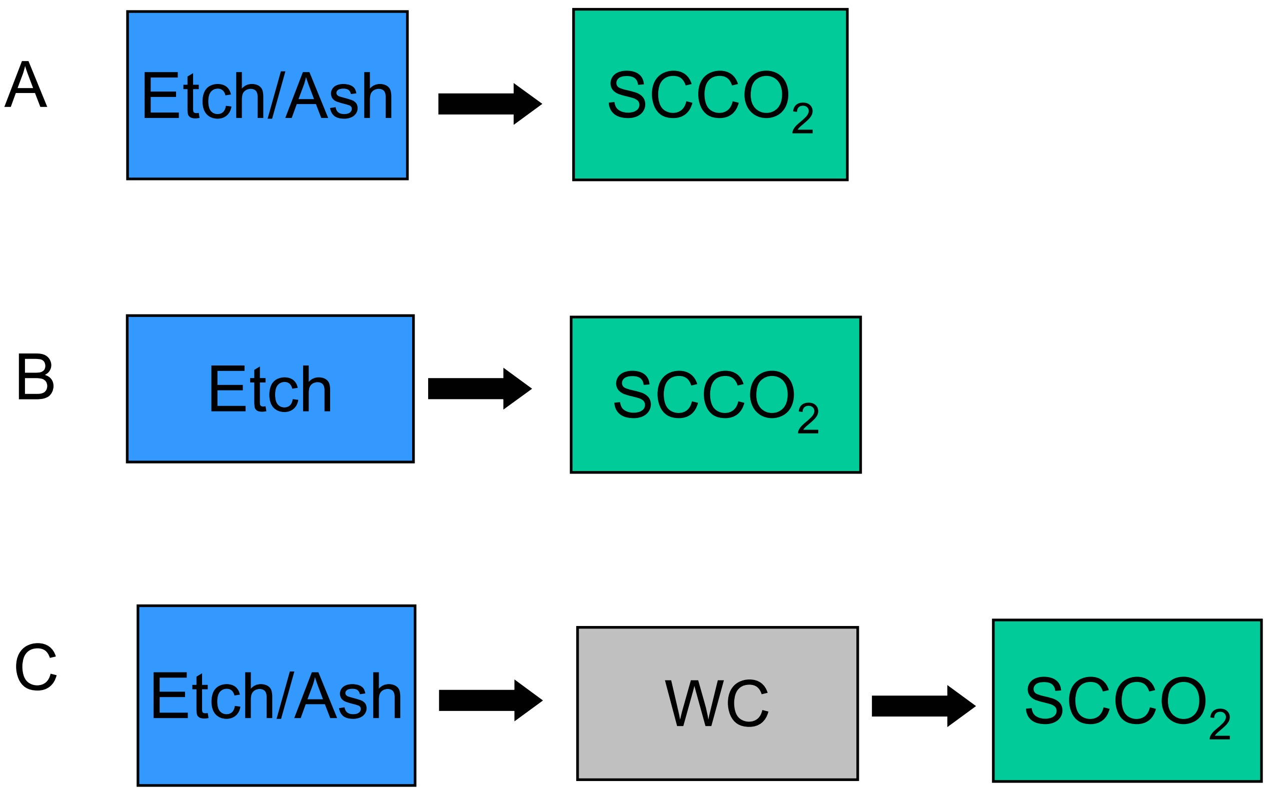
Semiconductor Applications

- Post-etch removal of Photoresist and Etch Residue
  - Post dielectric etch
  - Post metal etch
- Post-ash residue removal
- FEOL Cleaning
- k-value restoration
- Via poisoning
- MEMS Technologies
- Post CMP Cleaning

Advantages of $SCCO_2$

- Yield enhancement for sub 90 nm features
- Virtually no surface tension
  - can clean < 0.1 um CD
  - penetrates into the porous material
- Drying effect, extracts H_2O and organics
- "Dry in – dry out" process
  - leaves no residual solvent
- Compatible with porous low-k and Cu

Process Flows



Benefits

A: Residue Removal
k-value restoration

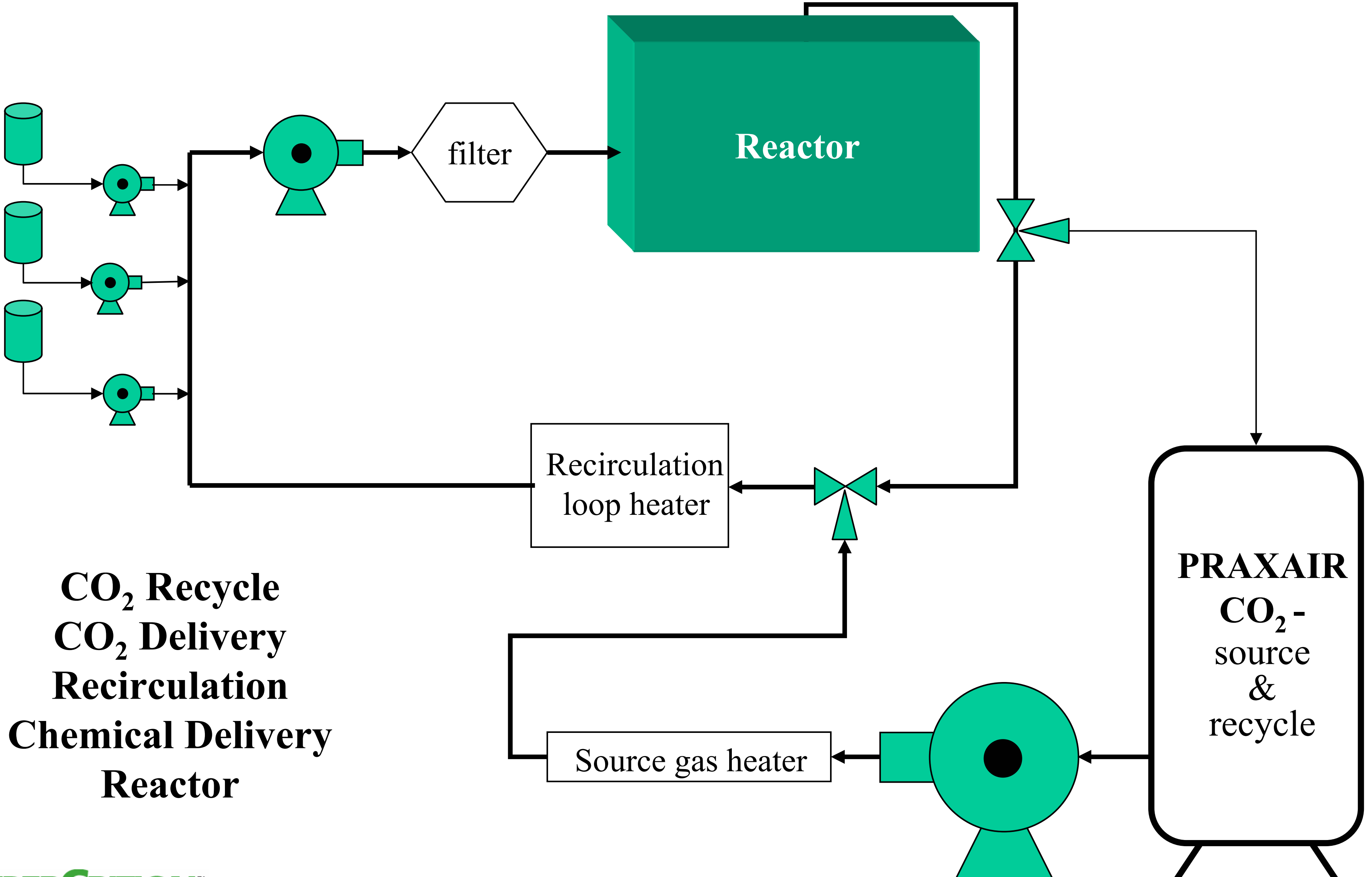
B: PR and Residue Removal
k-value restoration

C: Drying
k-value restoration

SSI Tools

- Process Development Lab
  - Bench Top Tools
  - Process development on wafer chips
- Process Integration Lab
  - α Tools
  - β Tools
  - Whole wafers runs
  - 200 & 300 mm option on all tools

Hardware



CO_2 Recycle
CO_2 Delivery
Recirculation
Chemical Delivery
Reactor

Process Conditions

- Typical process conditions:

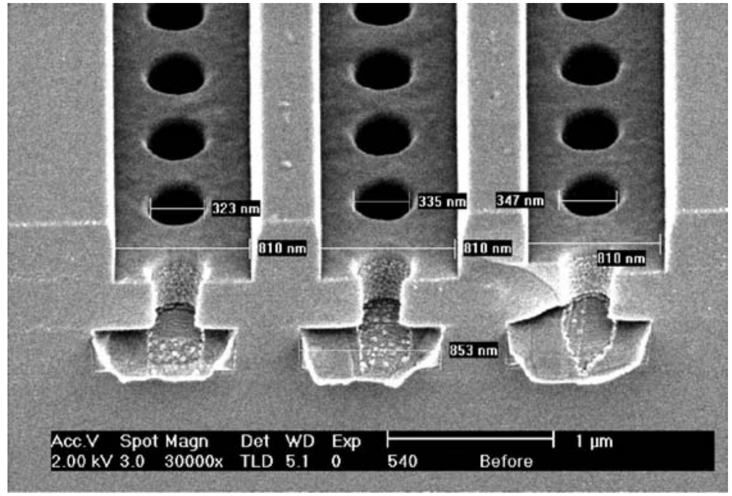
    - T = 40-80 °C
    - P = <3000 psi
    - Co-solvents: < 20 ml/wafer

Results

(Post dielectric ash residue removal)

Sematech – 540 (On Chips)

PRE



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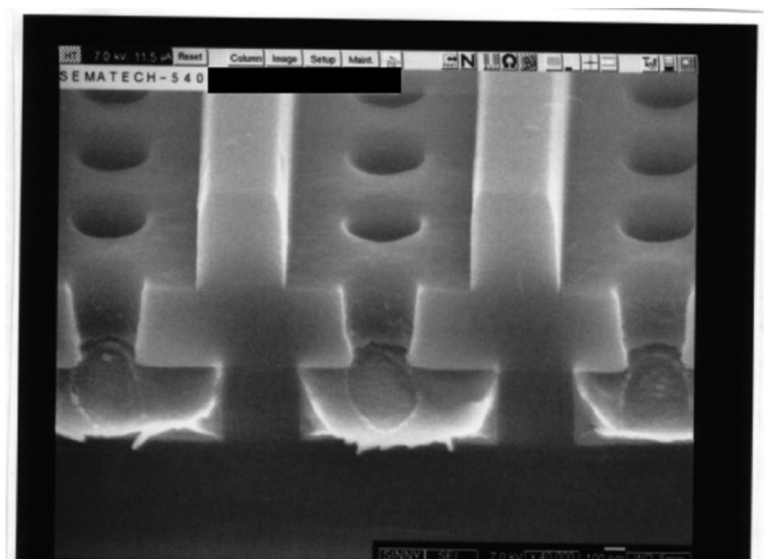
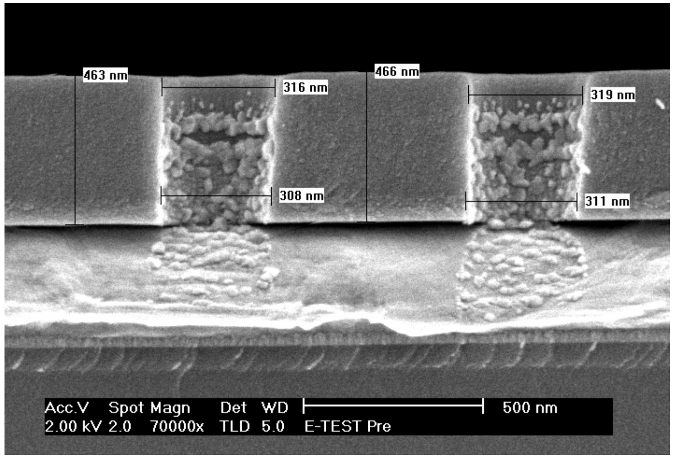
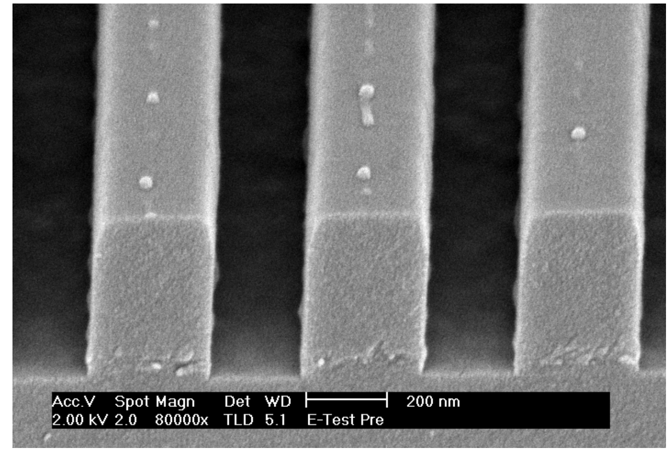


DD JSR Cu Wafers (On Chips)

Pre





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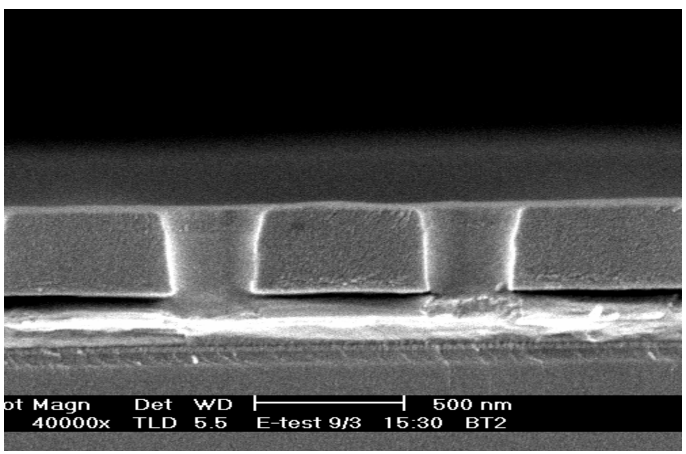

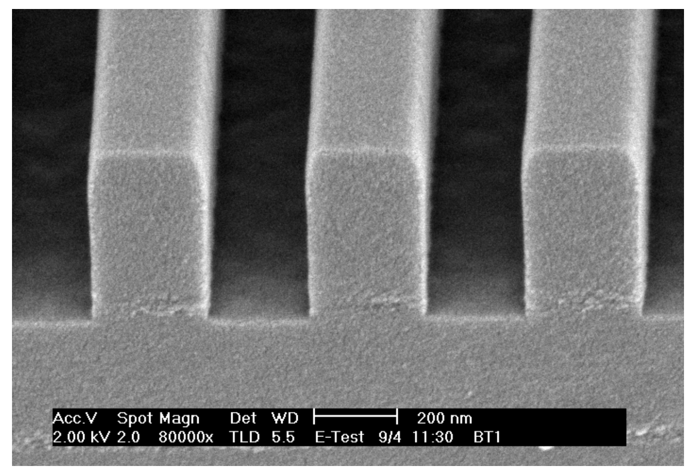

DD JSR Cu Wafers (On Chips)

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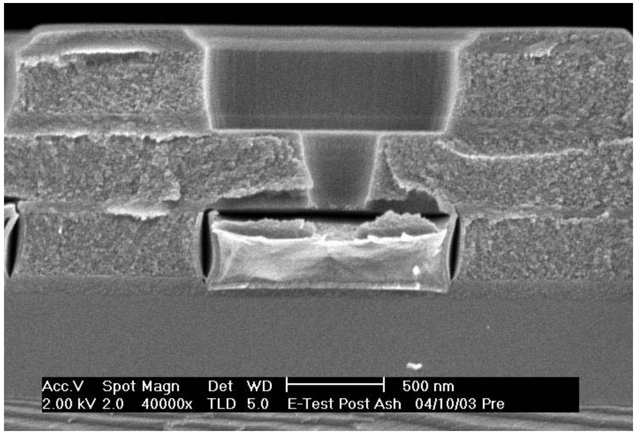

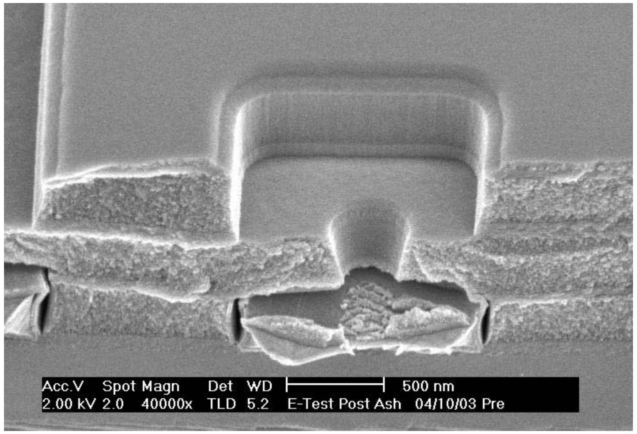

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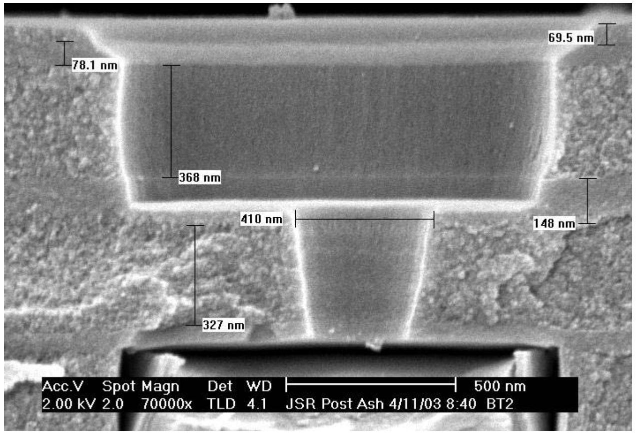
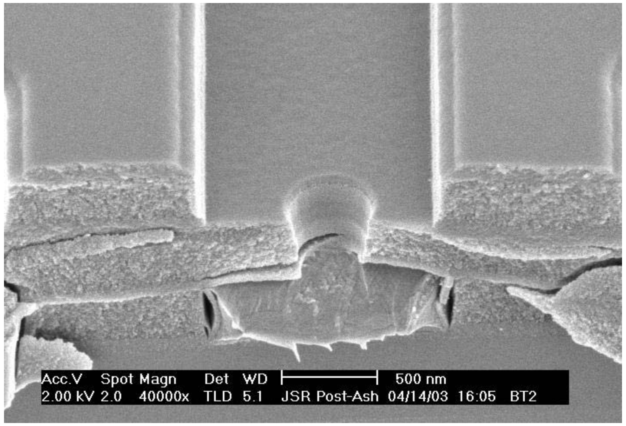


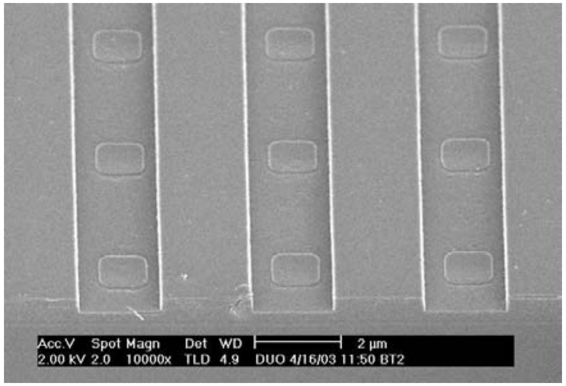


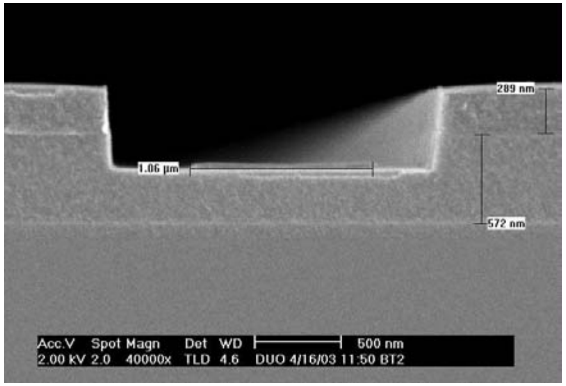
Results

(Post dielectric etch clean)

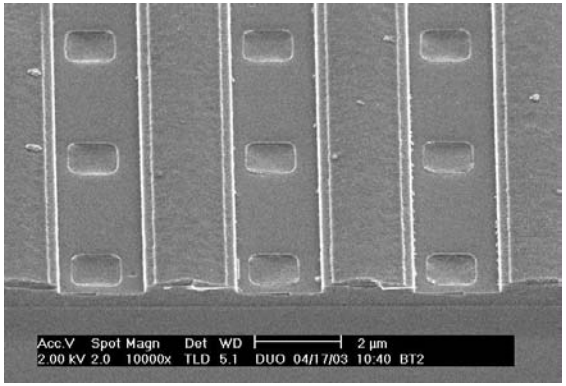
DUO Removal (On Chips)

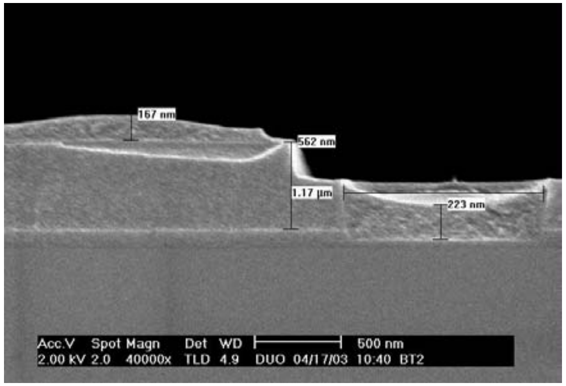
Pre



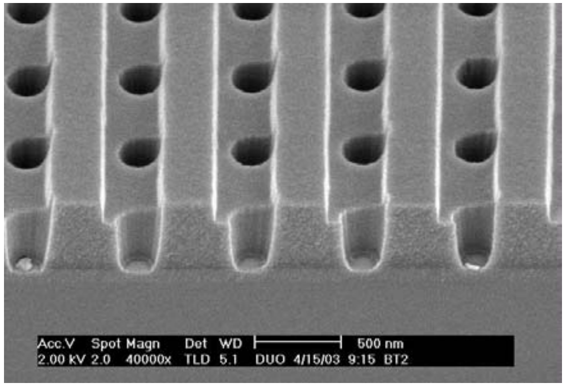


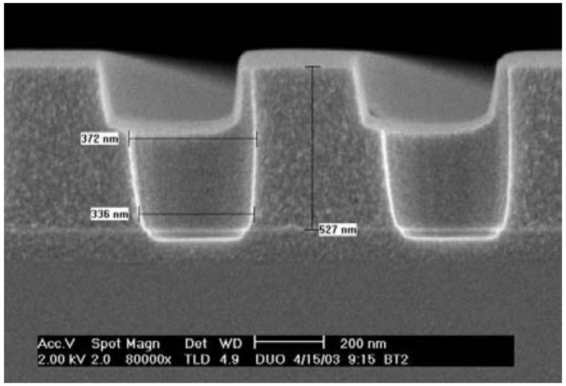
Post ½ BKM





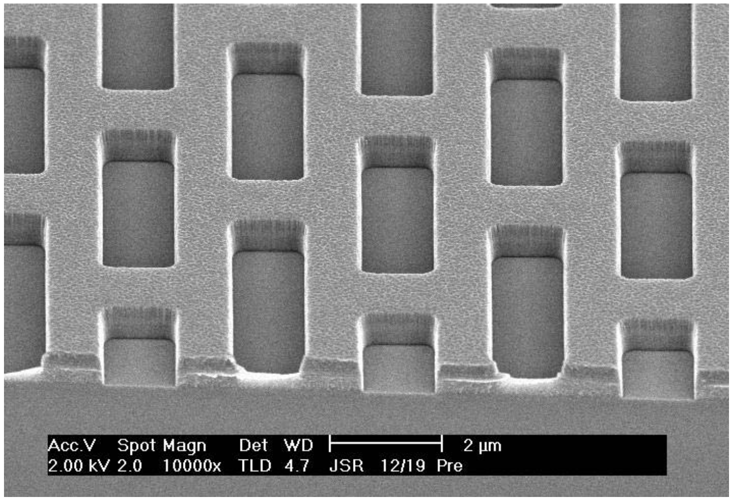
Post BKM

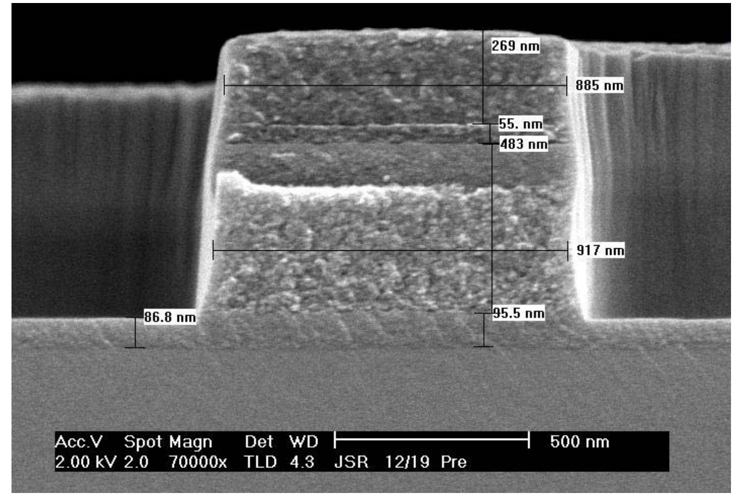




Sematech – JSR (On Chips)

PRE





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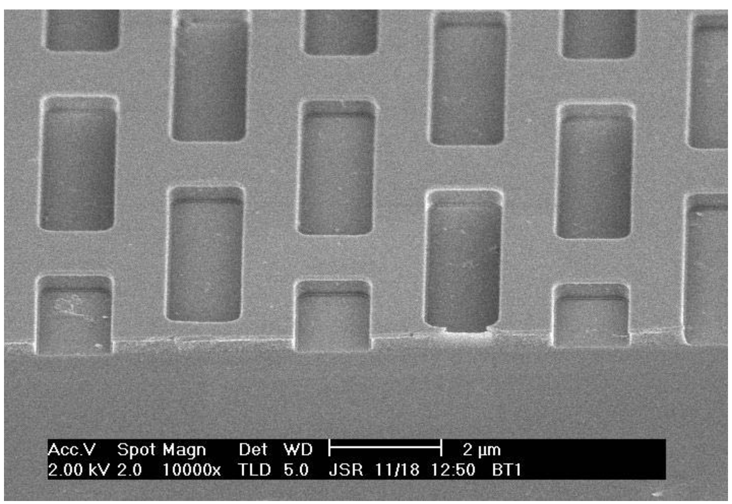
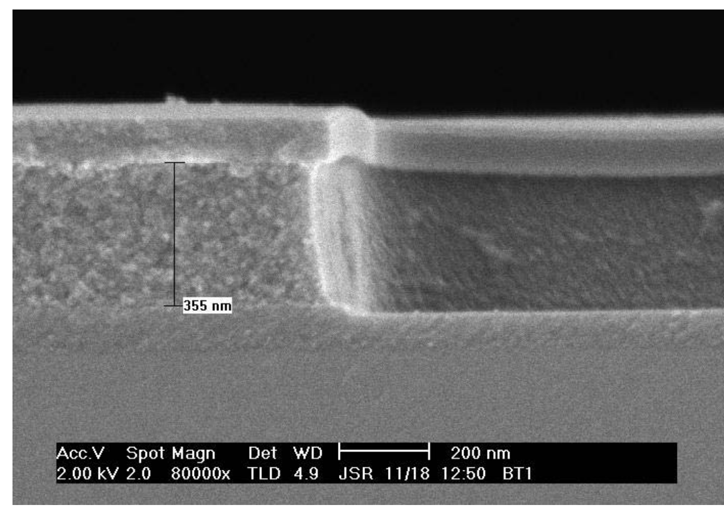
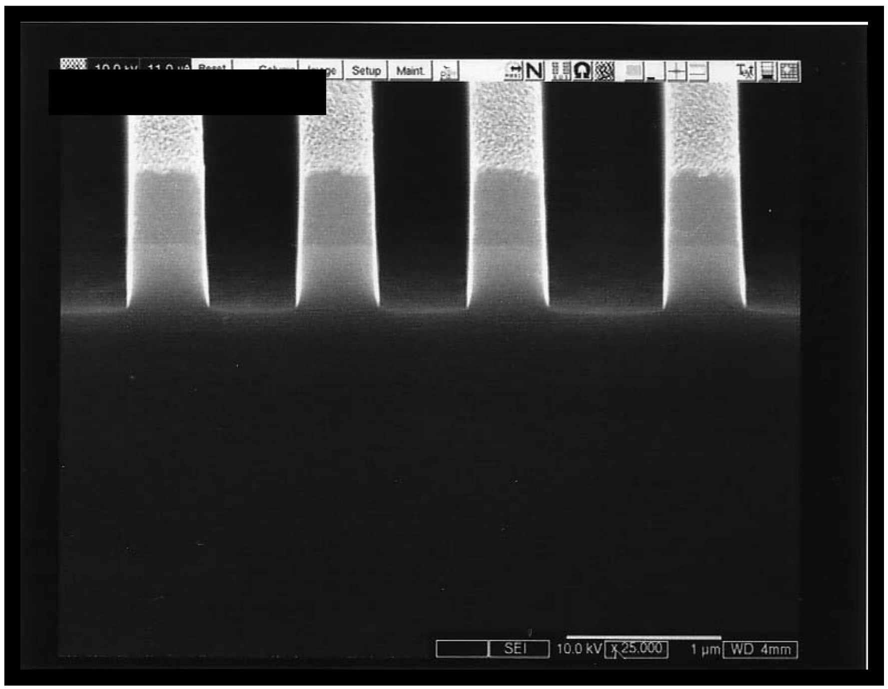


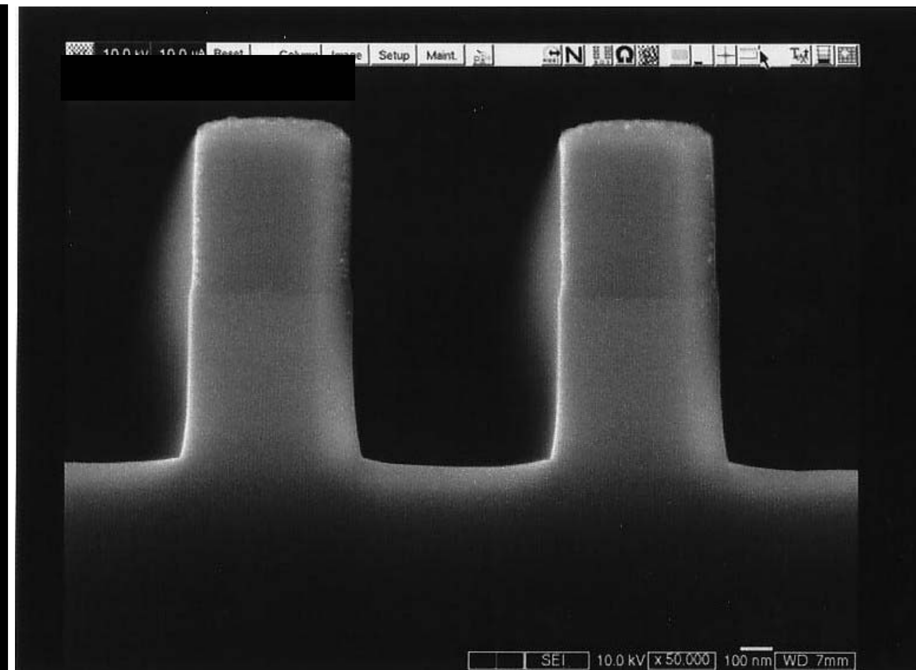


Cleaning of Low k Wafers

(Whole 300 mm Wafer)

Before $SCCO_2$ Cleaning

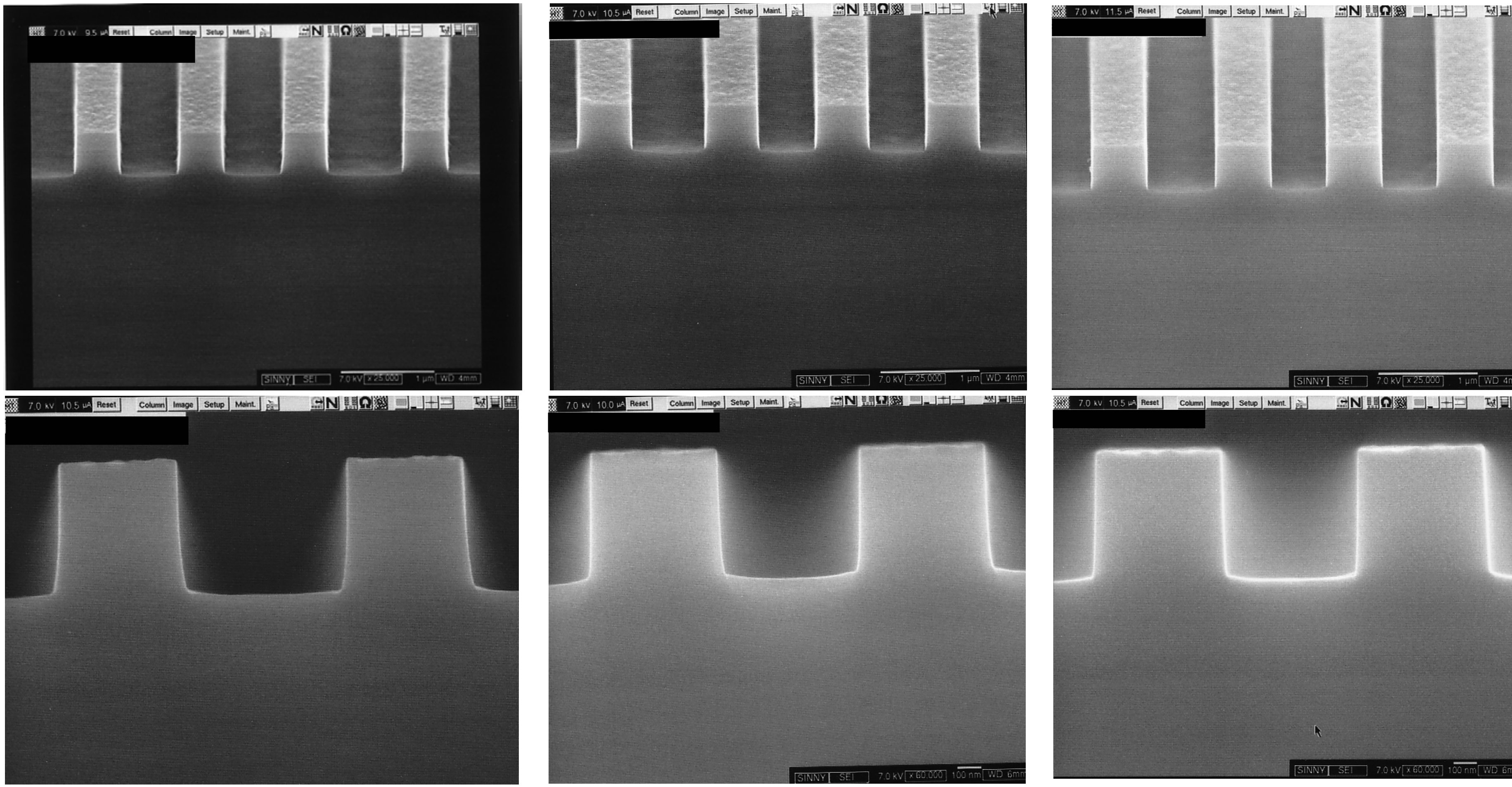




Cleaning of Low k Wafers

(Whole 300 mm Wafer)

After $SCCO_2$ & Co-Solvent clean

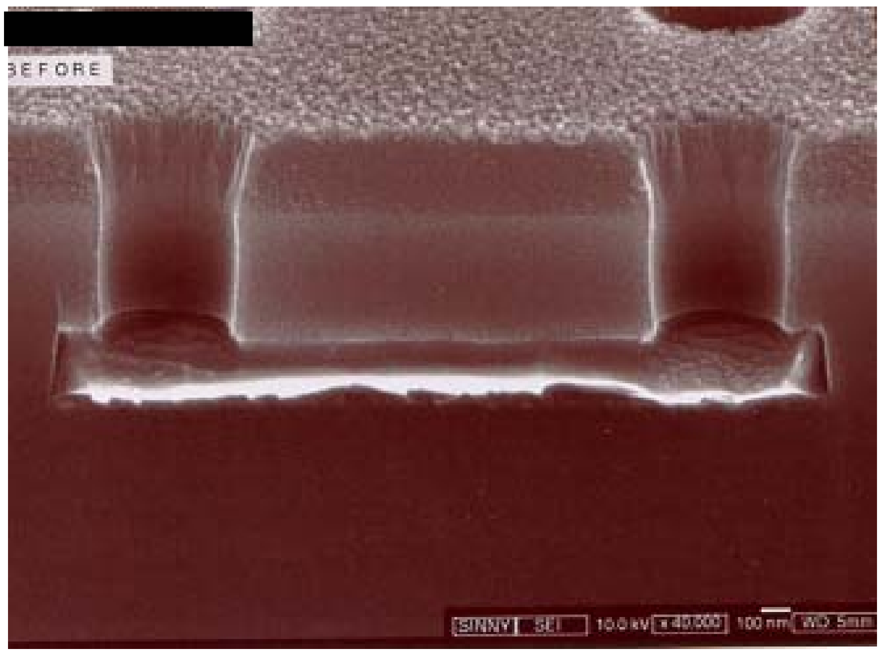


Center Mid-Radius Edge

Results
(Post metal etch clean)

Post metal etch (On Chips)

Pre



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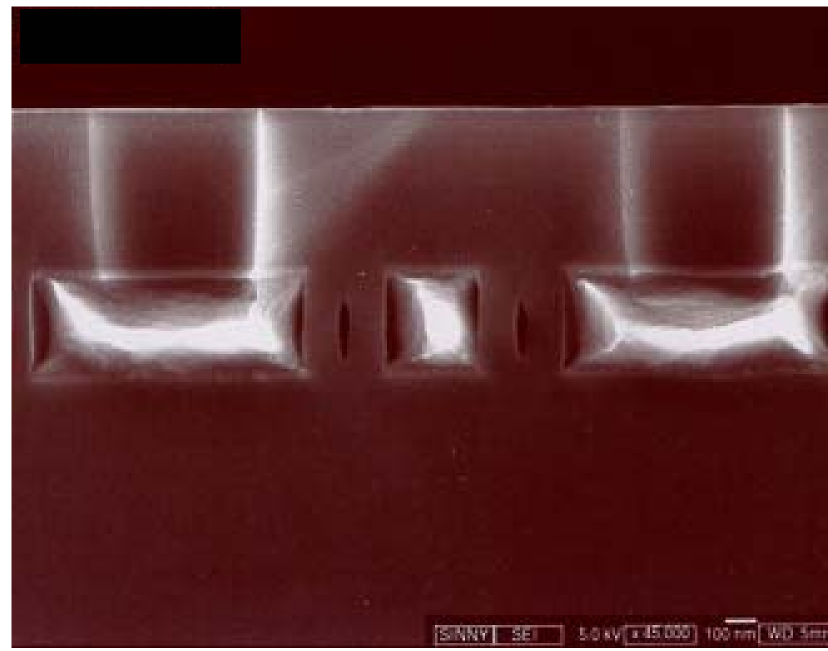
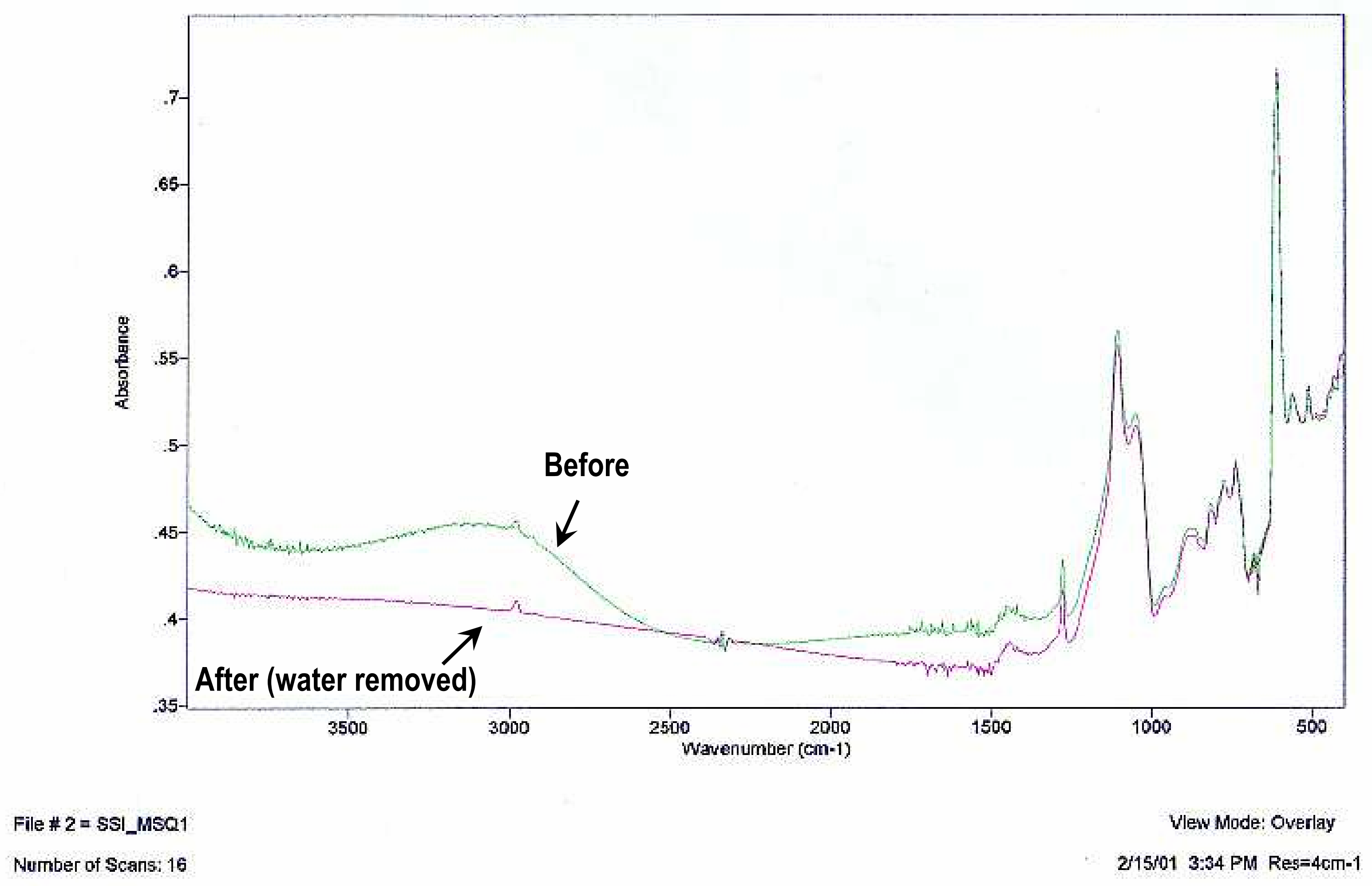


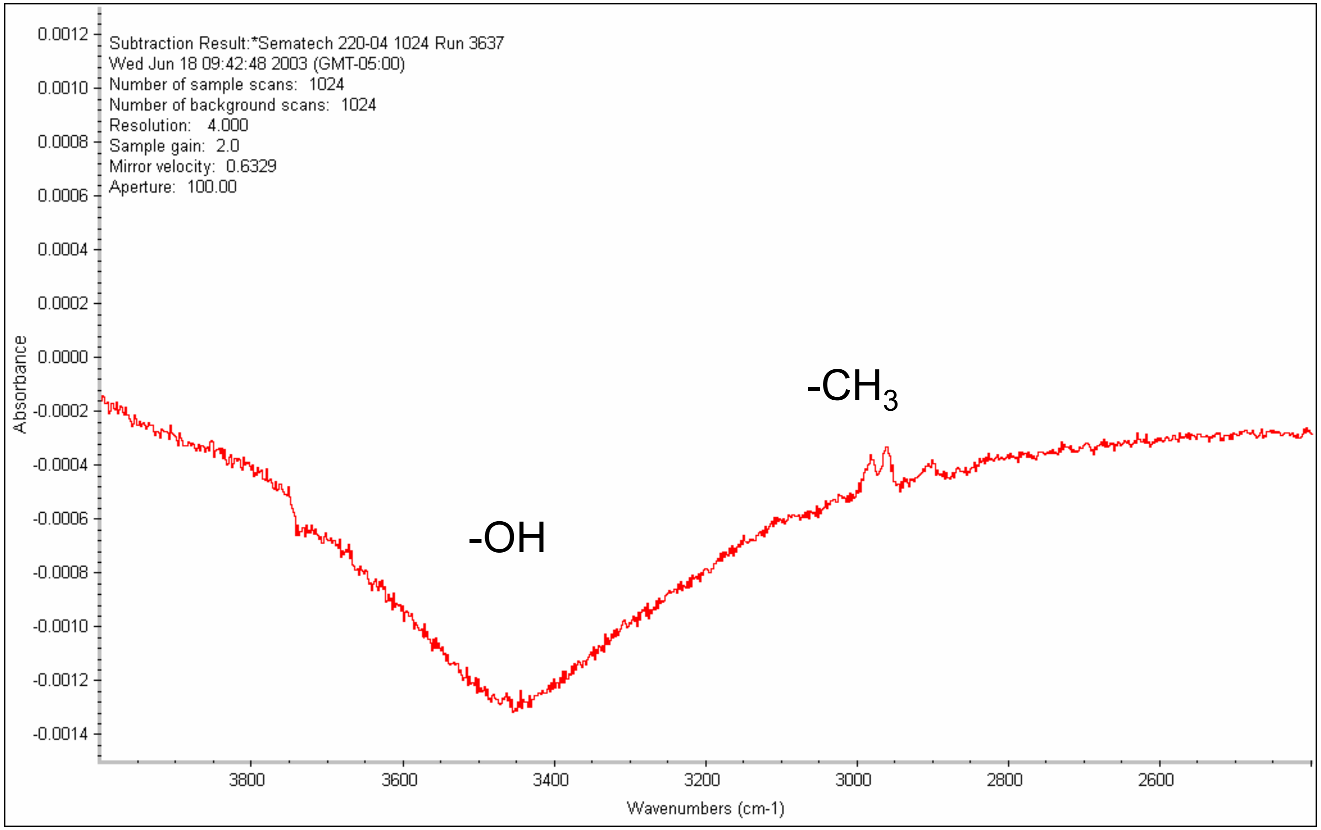
Results
(k - Value Restoration)

Moisture Removal



Blanket JSR Post He/O_2 Ash

FTIR subtraction of Pre and Post $SCCO_2$ HMDS

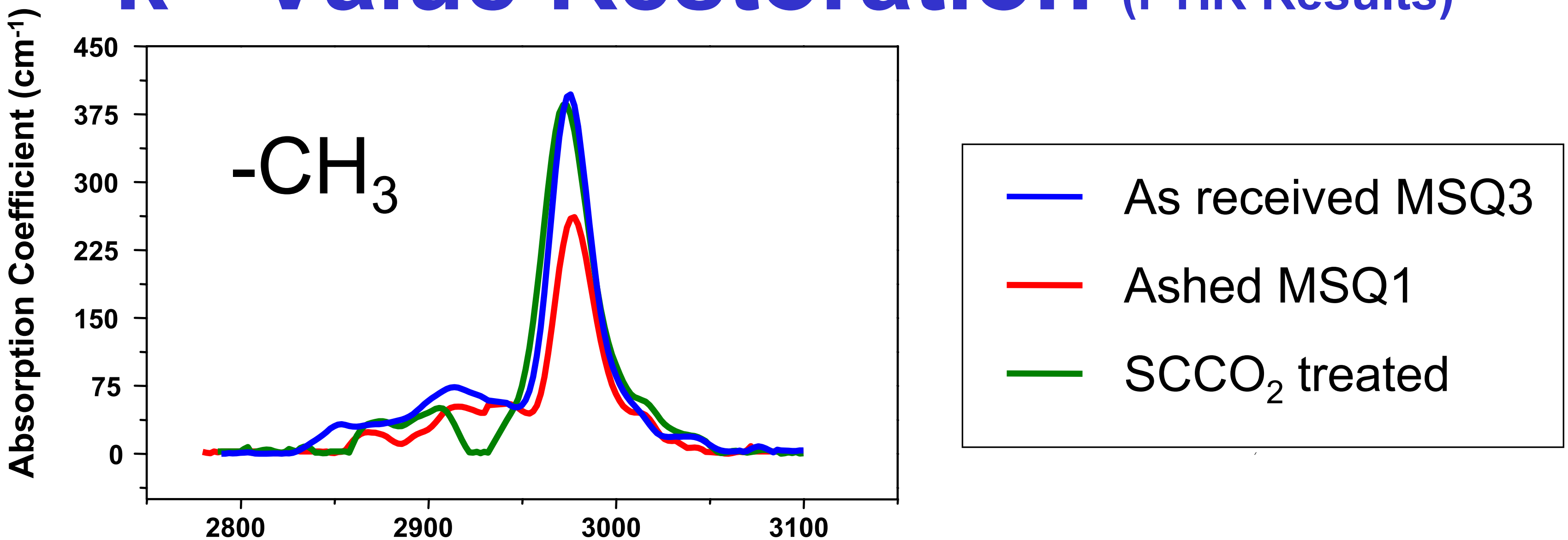


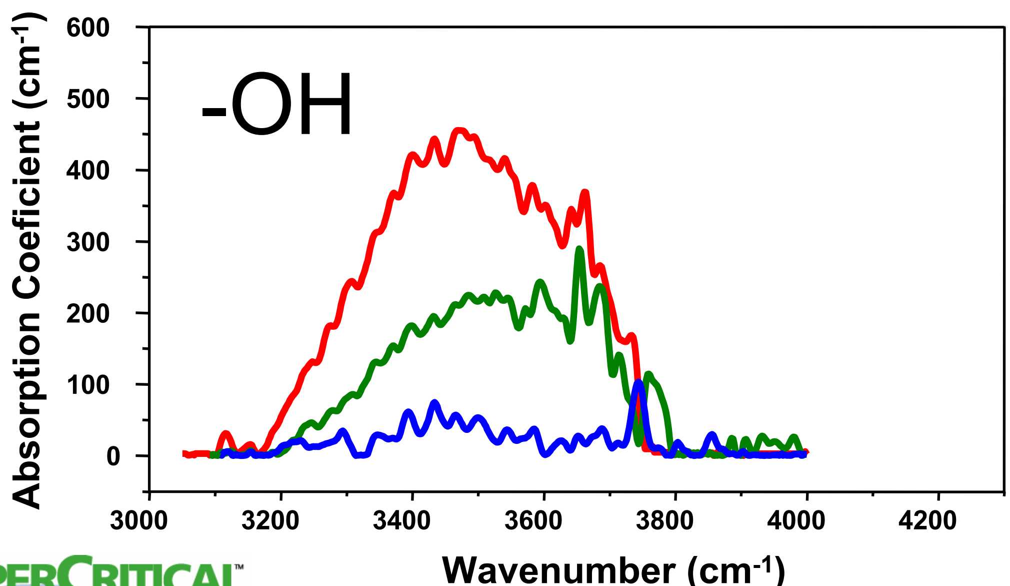
k-Value Restoration

- LKD films: MSQ1 (etched+N_2/H_2 plasma ashed)
  MSQ3: Untreated (4000 A)
- Static $SCCO_2$ (3000psi for 30mins) + HMDS (2%)
- C-V (k): MIS, Ti metal gate, 10 kHz
- FTIR (-CH_3 and -OH concentrations)

Data collected by US BEOL Process Technology Group

k - Value Restoration (FTIR Results)





SCCO2+HMDS →

- increase in $-CH_3$
- decrease in $-OH$

k - Value Restoration (k - Value Measurements)

Sample	K
MSQ3 (as received)	2.33
MSQ1 (ashed)	3.52
MSQ1: HMDS/$SCCO_2$	2.43

Data collected by US BEOL Process Technology Group

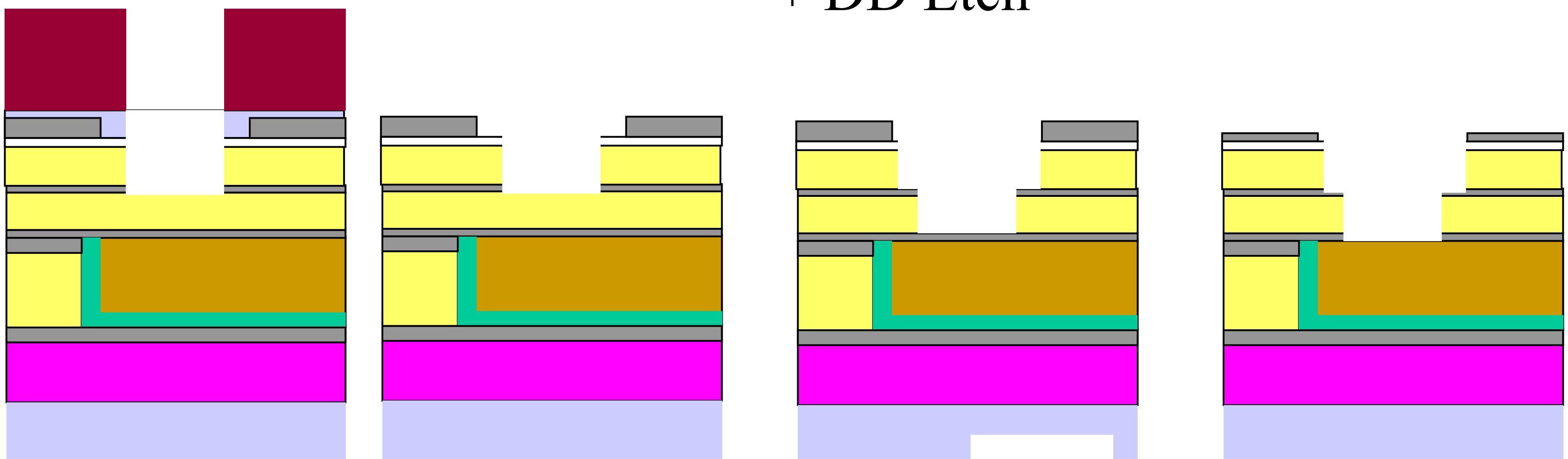
Results

(Electrical Results)

ULK post ash: E-test

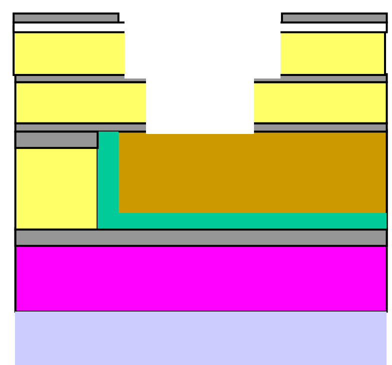
Sematech Trench First DD Flow

Etch Stop Layer Etch | O_2 Ash | Ox HM Etch + DD Etch | Cu Cap Etch



A) PR200Z: DIW clean

B) SSI Alpha-1: MeOH/HMDS



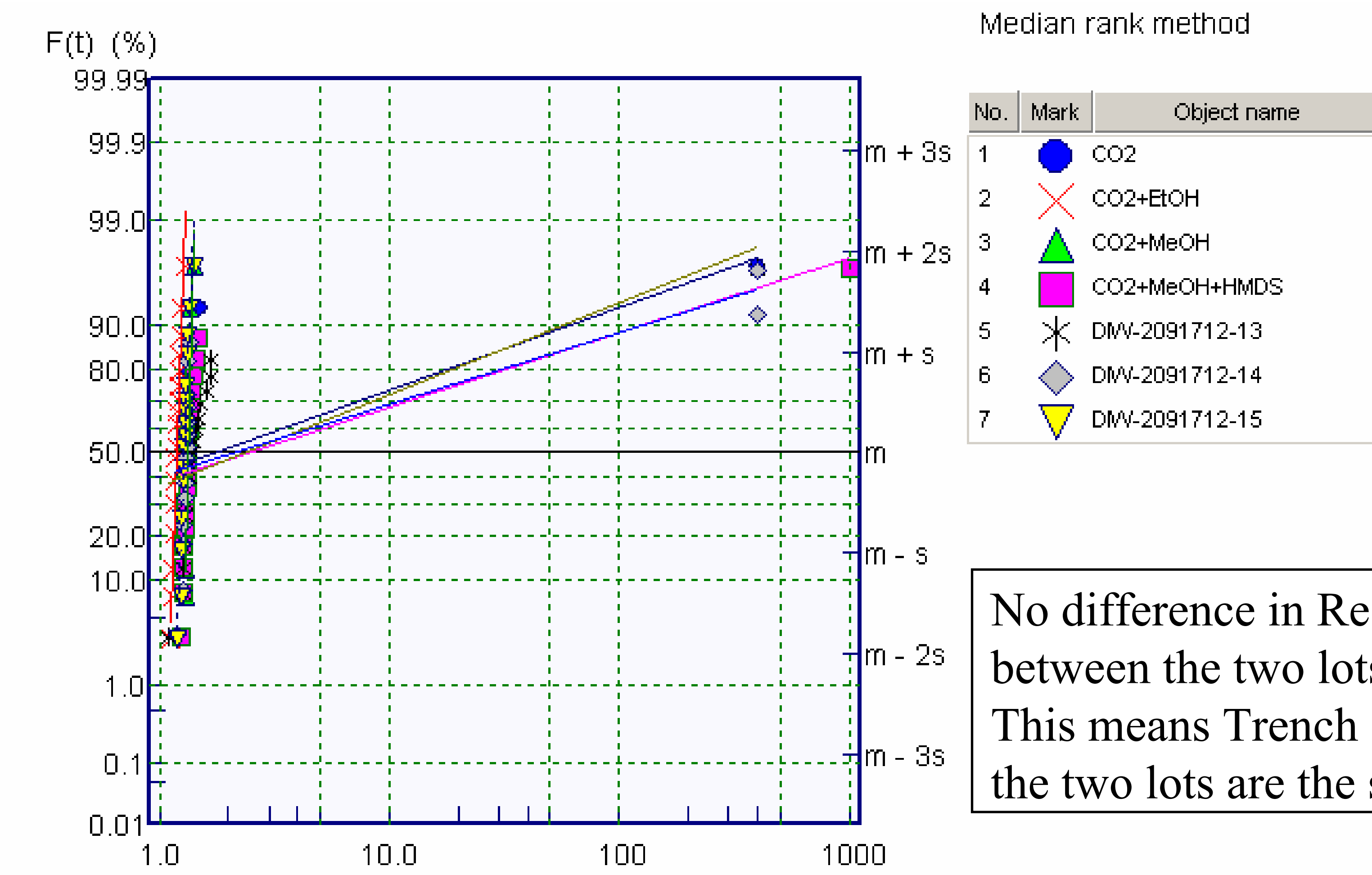
→ E-test

ULK post ash: E-test

Sematech JSR-DD Process Split

Lot No.	Wf.No.	Cleaning Tool	Cleaning Process
1092801B	21	SSI Alpha	CO_2 Only
1092801B	22	SSI Alpha	CO_2 + EtOH
1092801B	23	SSI Alpha	CO_2 + MeOH
1092801B	24	SSI Alpha	CO_2 + MeOH + HMDS
2091712	13	PR200Z	DIW
2091712	14	PR200Z	DIW
2091712	15	PR200Z	DIW

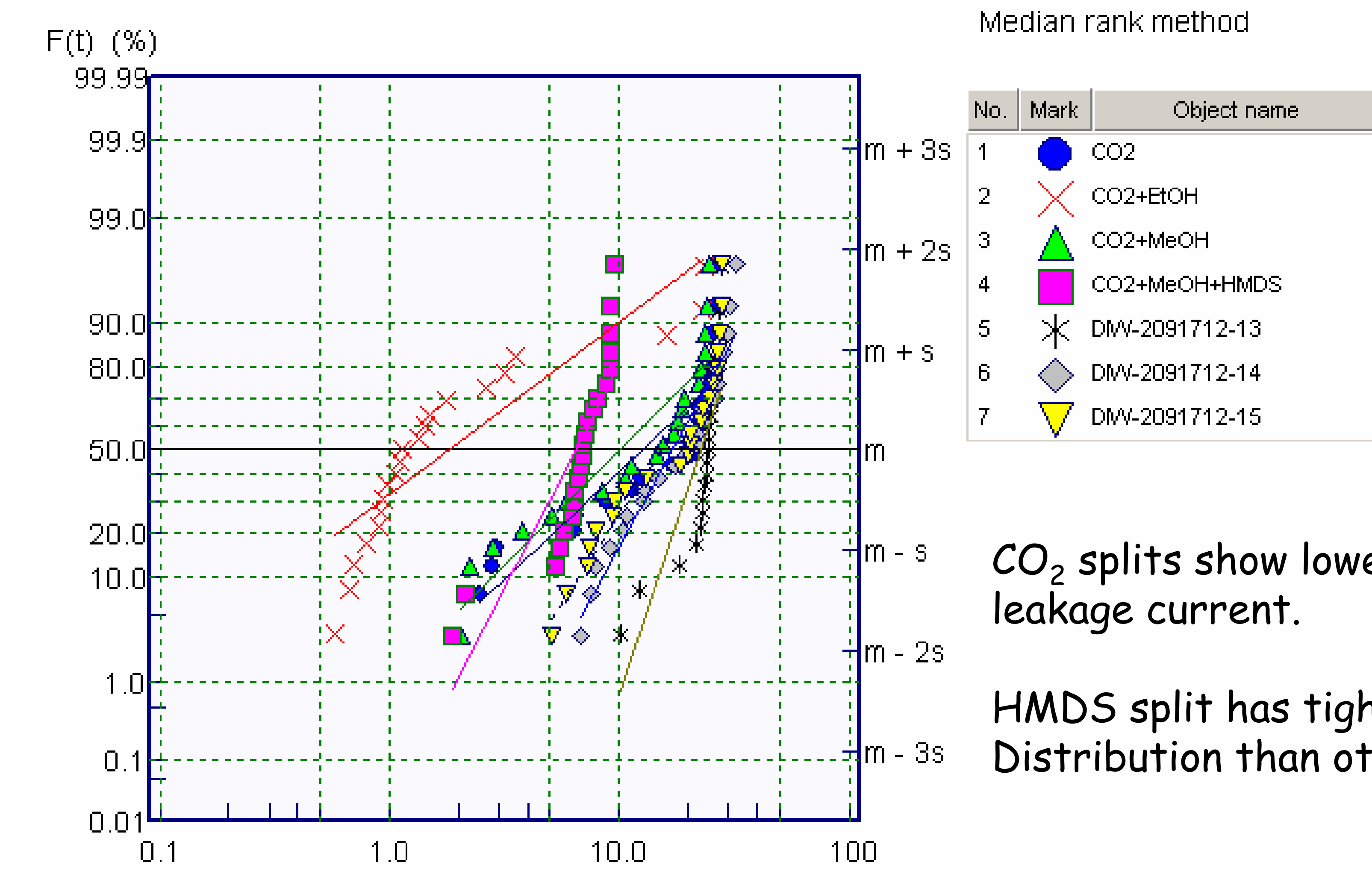
M2 Resistance 0.25um 64.8cm Long Serpentine



No difference in Resistance between the two lots.
This means Trench size of the two lots are the same.

M2-M2 Leakage

(0.25/0.3um, 64.8cm Long Serpentine)

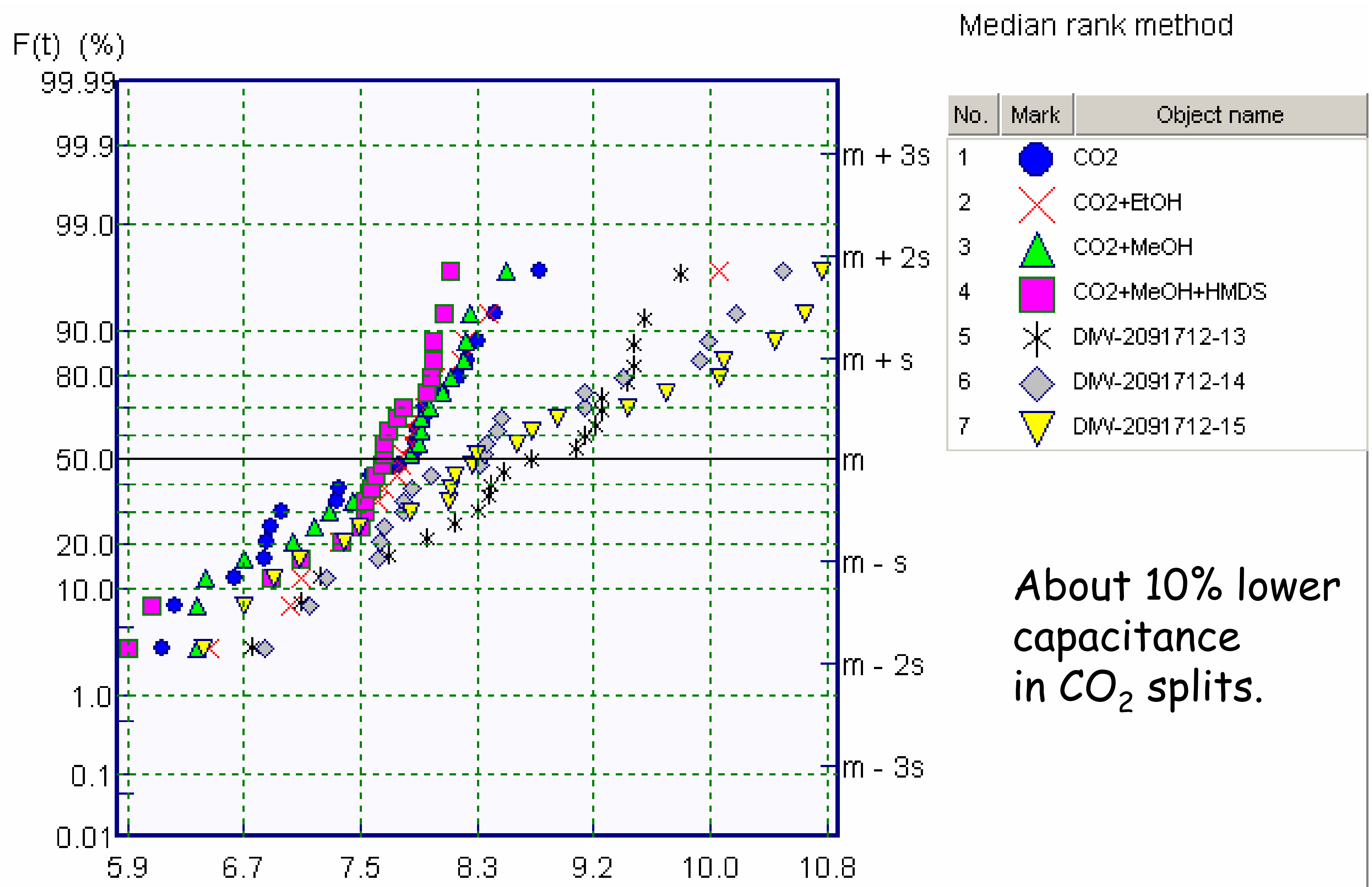


CO_2 splits show lower leakage current.

HMDS split has tighter Distribution than others.

M2 Capacitance

(0.25/0.3um, 114 Fingers, 9.12cm Perimeter)



About 10% lower capacitance in CO_2 splits.

JSR Post ash E-test data

- $SCCO_2$ treatment
  - EtOH used in $SCCO_2$ treatment was not semiconductor grade, i.e. this data not reliable.

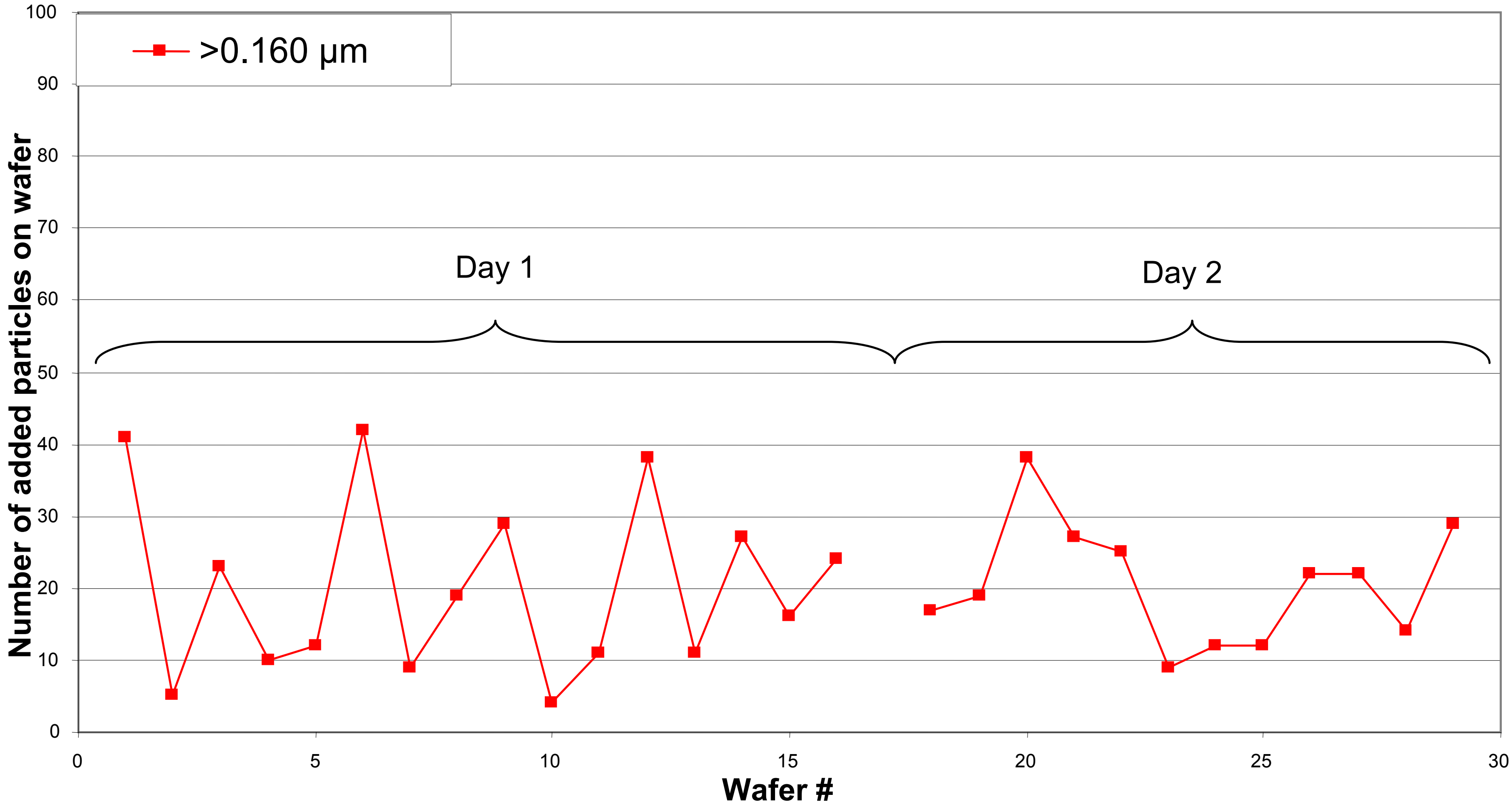
- Despite no clean before $SCCO_2$, improved E-test data was obtained

Results

(Defects)

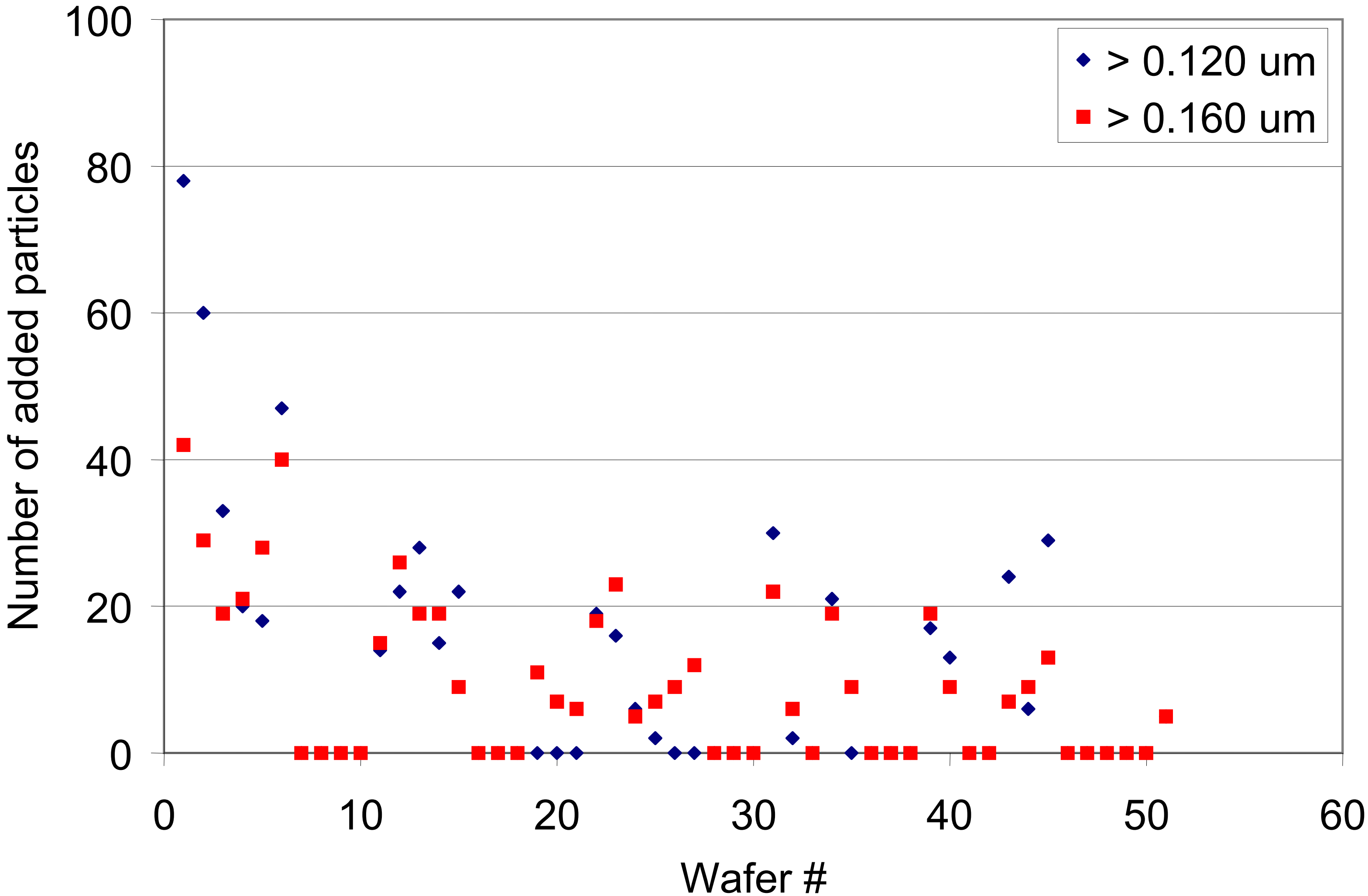
Particle Data from α - Tool

(CO_2 & Process Chemistry)

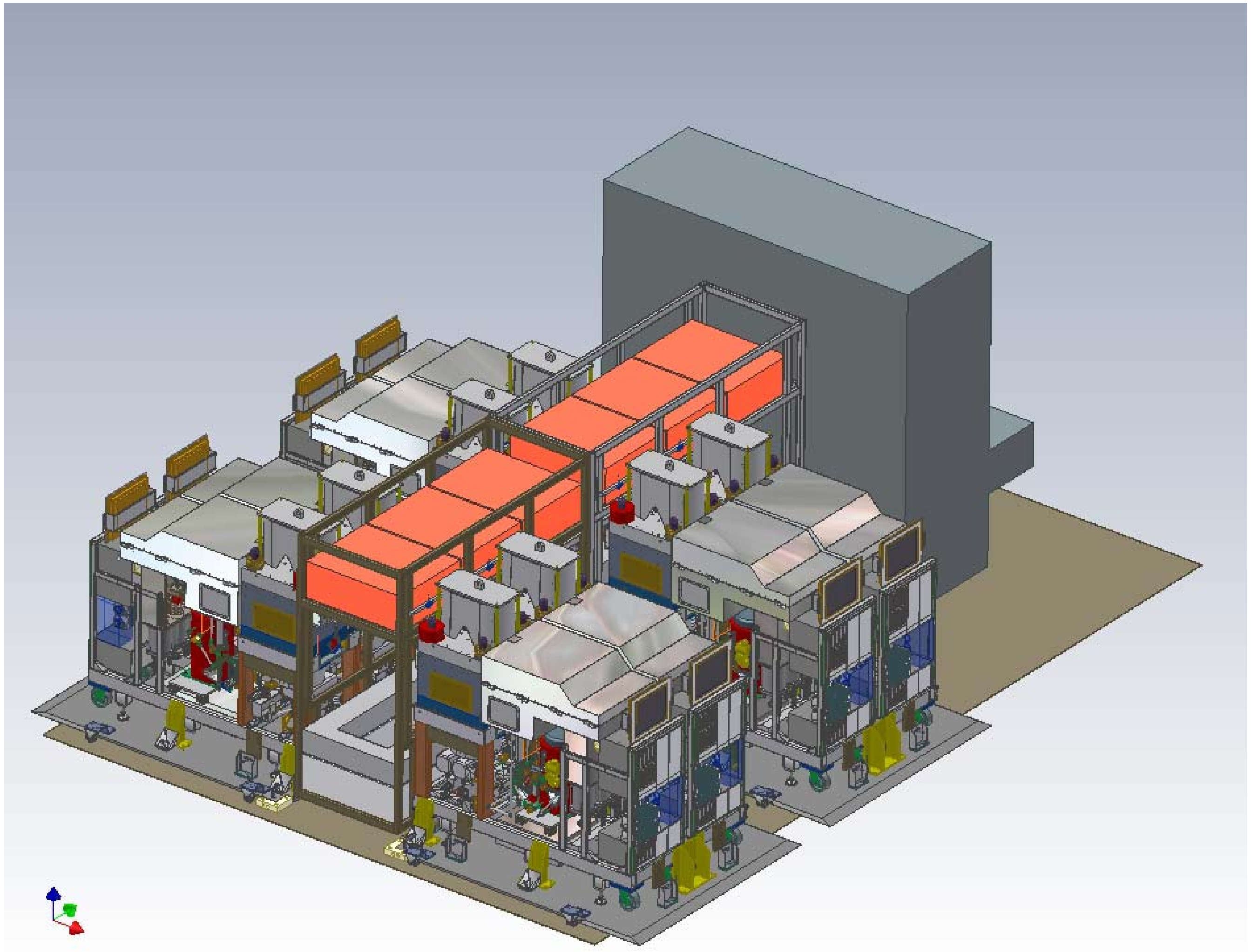


Particle Data from MCM 300

(CO_2 only)



β Tool MCM300



β Tool

1300 lb/hr High Pressure Skid

Recycle Skid

- CO_2 Purification and Delivery System
- Recycles and treats spent CO_2 exhaust
- Recovers CO_2 for reuse
- Separates and removes heavy organic compounds
- Delivers CO_2 at 1000 psig
- 100 lb/hr capacity
- CO_2 supplied from dewar at 300-400 psig
- Purification Process
  - Expansion
  - Distillation
  - Compression
  - Liquefaction

Summary

- Supercritical CO_2 based cleaning is effective for removing photoresist and etch/ash residue
- No surface tension allows for cleaning <0.10 μm CD
- k-value restoration by repairing CDO and drying
- Process is compatible with porous Dielectrics
  - No Damage
  - Moisture Removal
  - Enhanced electrical properties