Self-aligned Contact Etch Development for 90 nm Technology Node

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Outline

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- *Next Generation Technology (eMAX)*
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- *Optimization Challenges*
- *Optimized Process*
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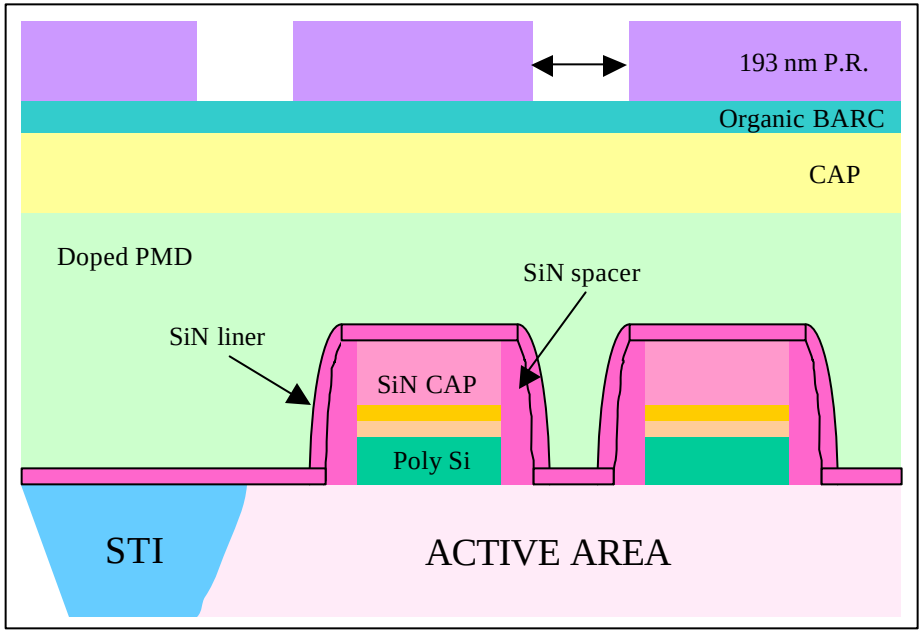
- *Next Generation SAC Etch Challenges*
- *Summary*

Background

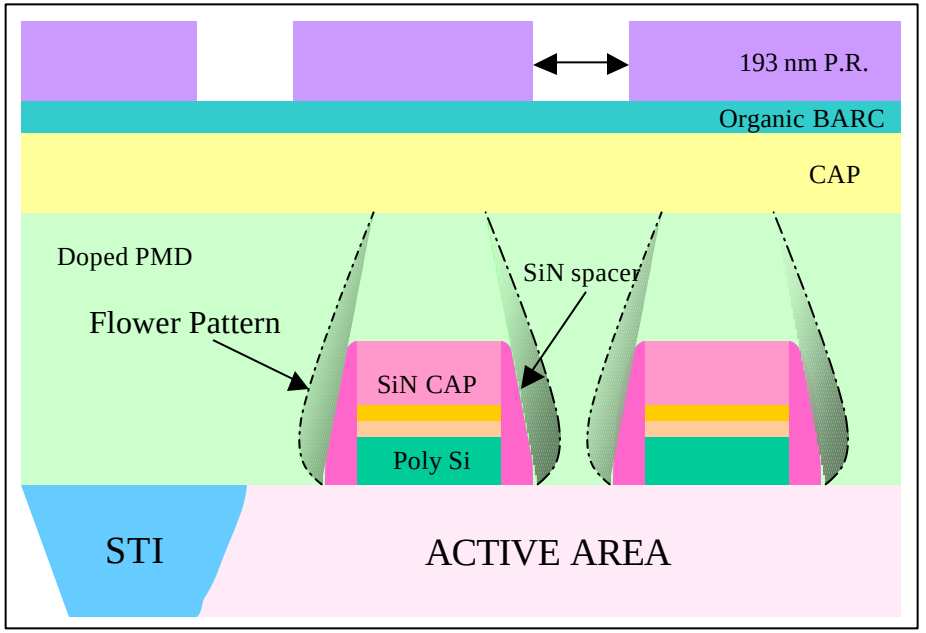
- *Industry demand for high density memory products and quest for packing more dies/wafer have driven the memory cell size shrink.*
- *Self-aligned and borderless contacts, by relaxing lithography alignment requirements, have been two of the most powerful engines for cell size reduction.*
- *Self-aligned contacts (SAC) are used to form contacts to source and drain area.*
- *General electrical requirements for SAC:*
  - *Low contact resistance*
  - *No break-down to gate at operating Vcc*
  - *No leakage at corner of STI*
- *Self-aligned characteristics are obtained by employing chemistries that:*
  - *Anisotropically etch PMD (i.e. undoped or lightly doped glass)*
  - *Does Not etch the spacer and gate protection cap (i.e. Si_3N_4)*
  - *Stops on a thin liner (i.e. Si_3N_4)*
- *Contacts to S/D are subsequently formed by:*
  - *Removal of the liner by employing a plasma etch selective to Si and STI (HDP SiO_2).*
  - *Liner and plug deposition followed by CMP to polish to PMD surface.*

Stack and Architecture



* not drawn to scale

Conventional SAC Architecture

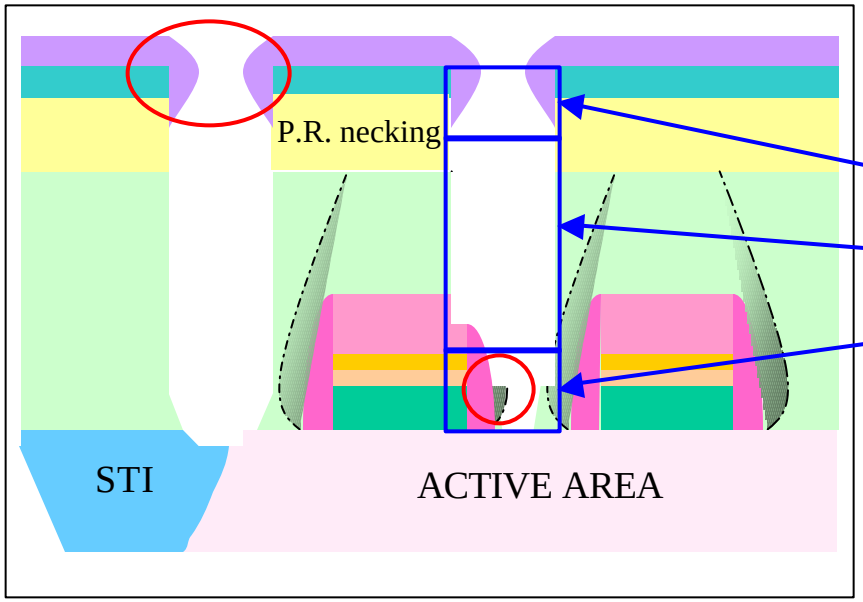


* not drawn to scale

Cypress SAC Architecture

- *Cypress SAC architecture increases contact area (reduces cell size) by eliminating liner*
- *It requires to etch doped glass and stop on HDP oxide*
- *It introduces the so called "flower patterns", hard to etch (possibly due to back-sputtered Si)*

SAC Etch. Characteristics vs. Requirements



3-step Etch Process:
1- ARCE
2- M.E.I
3- M.E. II

* not drawn to scale

Characteristics

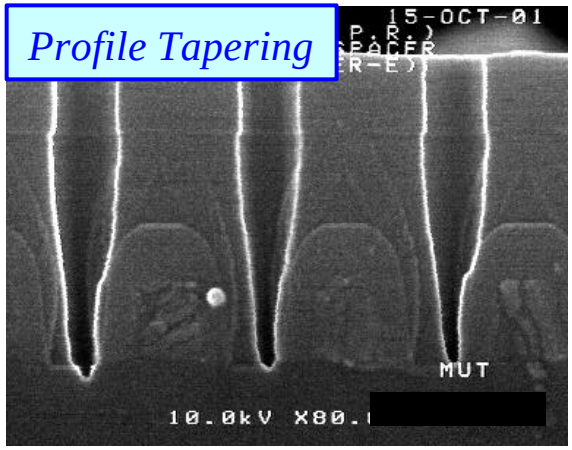
- *Soft and thin 193 nm P.R.*
- *Organic BARC*
- *Highly doped PMD*
- *No stop liner*
- *Flower Pattern*

Requirements

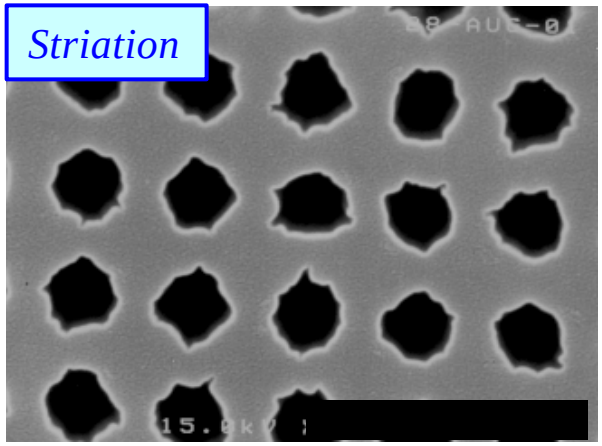
- *Minimum +ve CD Bias (< 15 nm)*
- *Straight Profile (>87°)*
- *No P.R. Necking*
- *No striation*
- *Maximum SiN shoulder loss <400 A*
- *Maximum STI gouge <300 A*
- *No sensitivity to flower pattern*
- *Ability to etch O.L. trenches (1x20 mm)*

Performance of PTOR (Super-E/C4F8-CO)

Profile Tapering



Striation



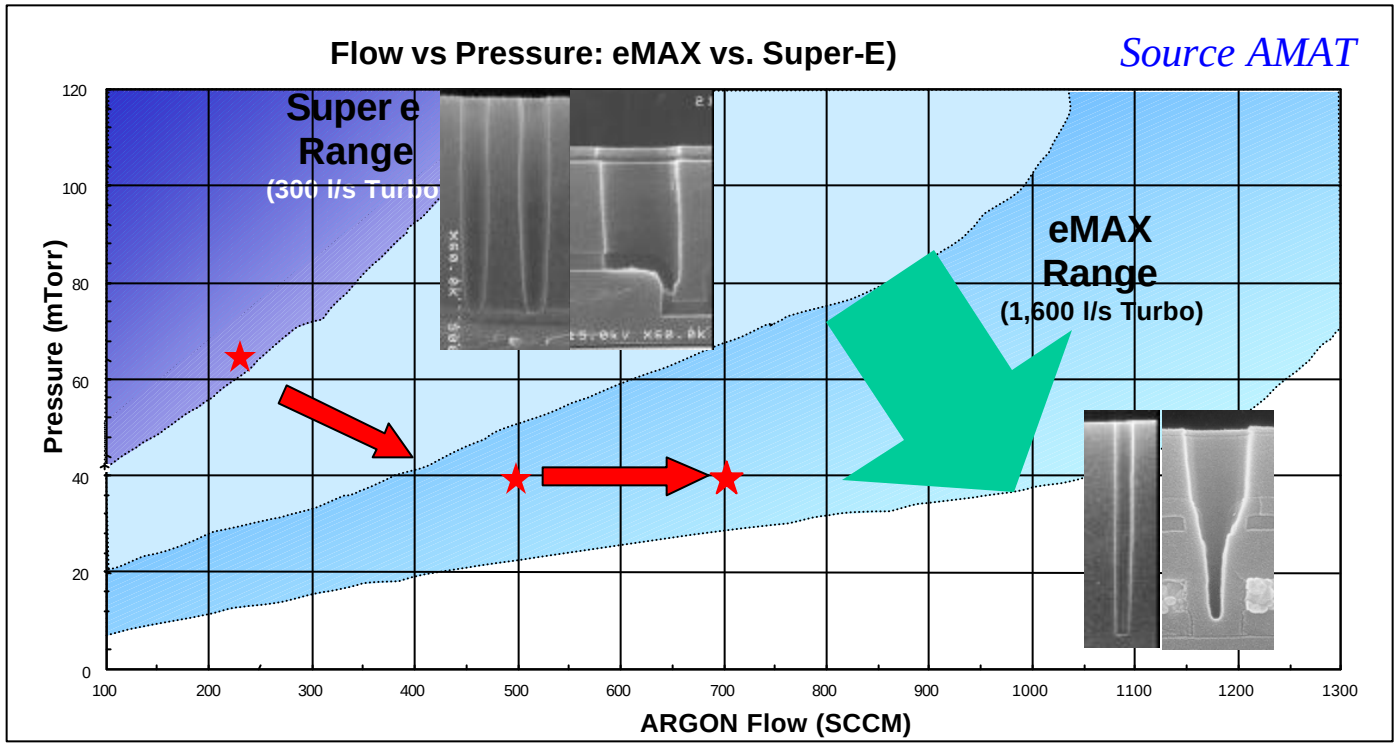
Problems:

- *Severe profile tapering*
- *P.R. Pinch off*
- *Severe top contact striation*

Solutions:

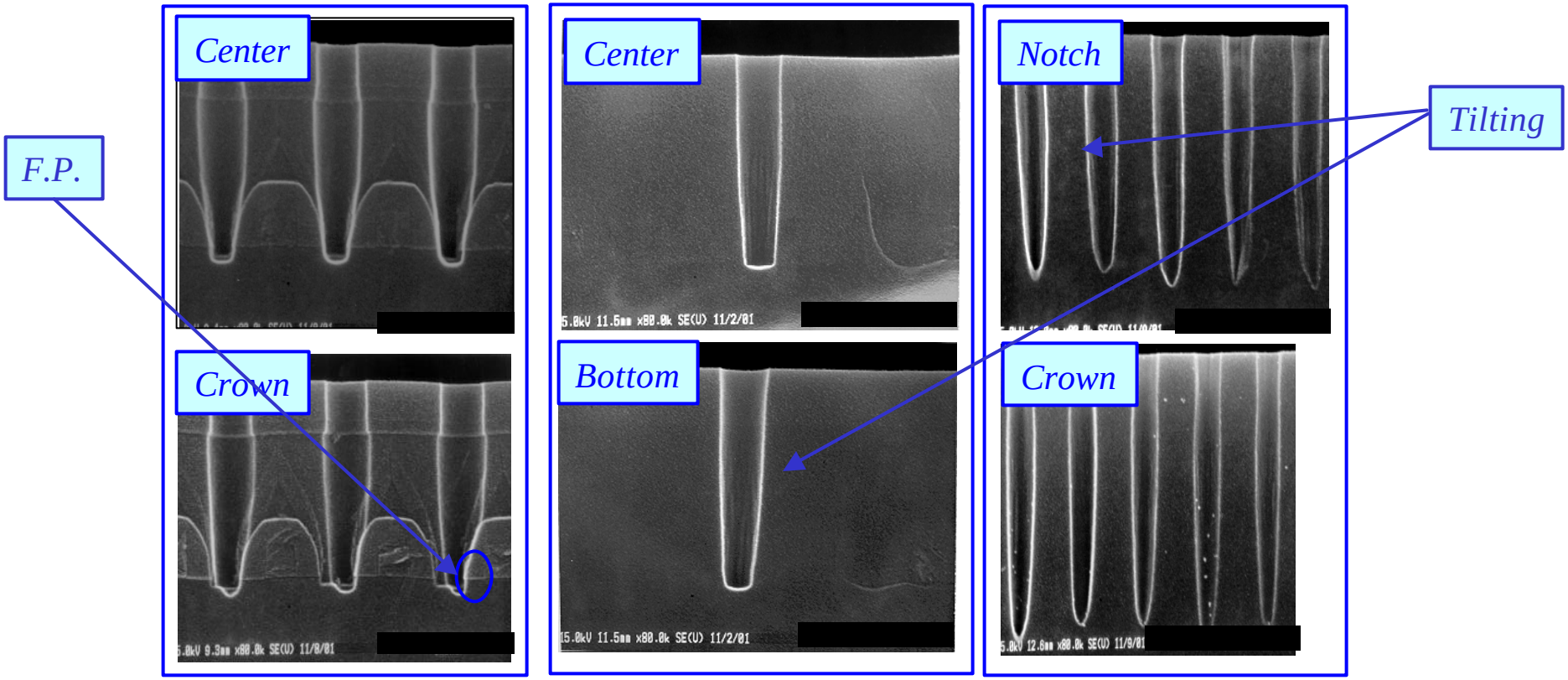
- *Migrate to high flow-low pressure region* → *Adjust residence time*
- *Use lower temperature process*
- *Use alternative chemistry with higher P.R. selectivity*

Next Generation Technology (eMAX): Characteristics



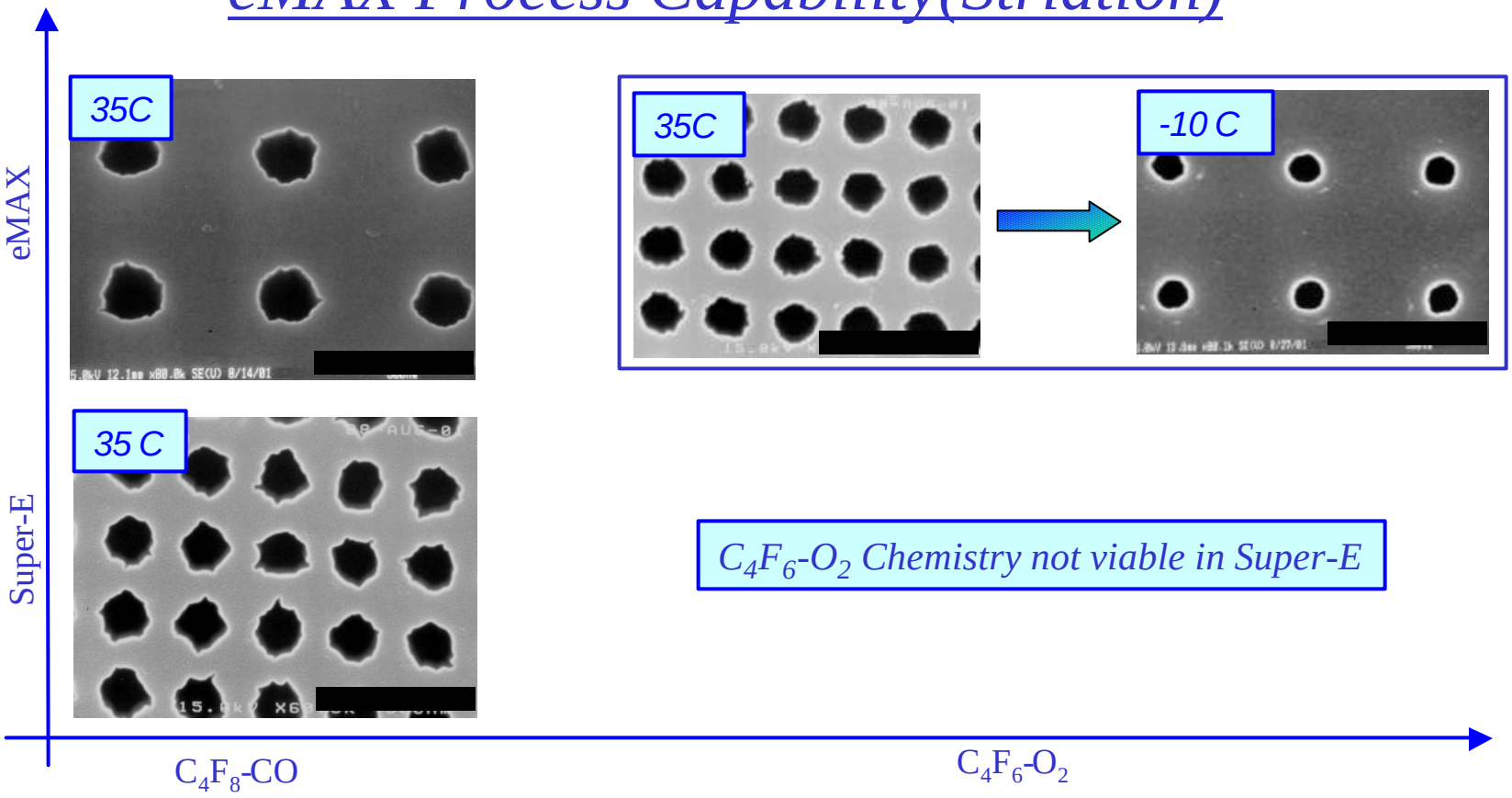
- *High flow-low pressure region : high C:F chemistry in starving mode*
- *Temperature controlled liners: better polymer deposition*
- *Wider range B-field: control uniformity and ion energy*
- *Wider range backside He pressure: independent interstep temperature control*

eMAX Process Capability (C4F6-O2)



- C_4F_6-O_2 process in eMAX improved the profile, reduced P.R. pinch off (not eliminated).
- Overall process also achieved acceptable Si_3N_4 and SiO_2 selectivity.
- Contact profile tilting observed at the wafer edge (<6 mm edge exclusion).
- Sensitive to flower pattern.

eMAX Process Capability(Striation)

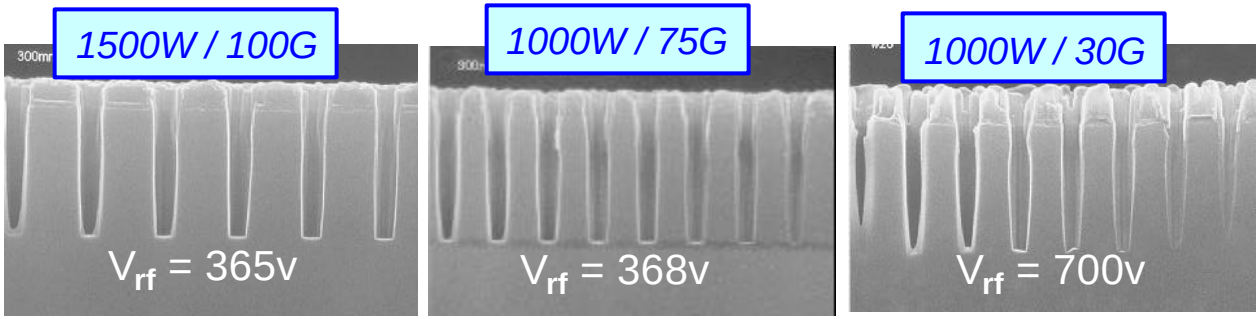


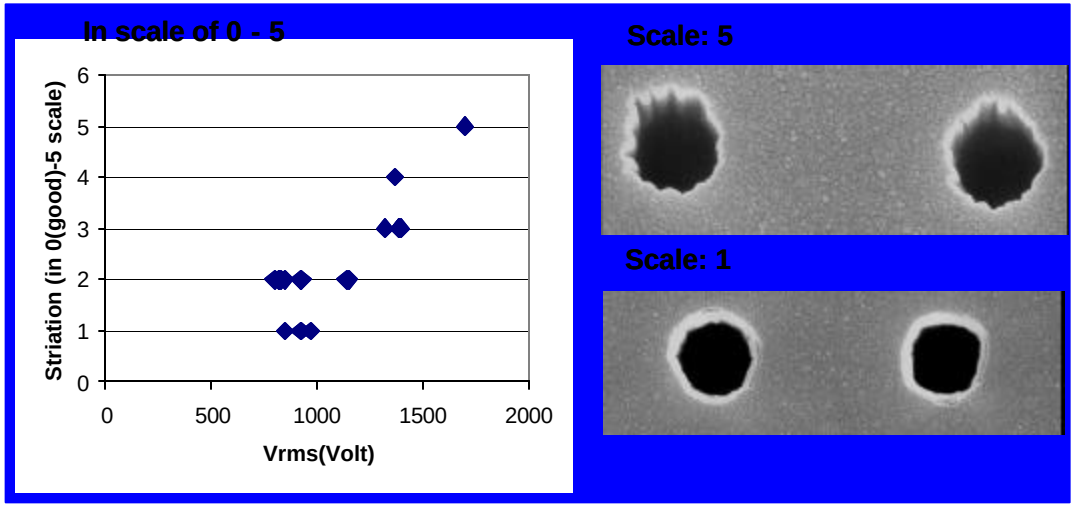
C_4F_6-O_2 *Chemistry not viable in Super-E*

- *Striation was reduced by using eMAX and C_4F_6-O_2 chemistry.*
- *Using low temperature, however, not viable due to SiO_2/Si_3N_4 selectivity requirements.*
- *Achieving an acceptable process requires further hardware modifications.*

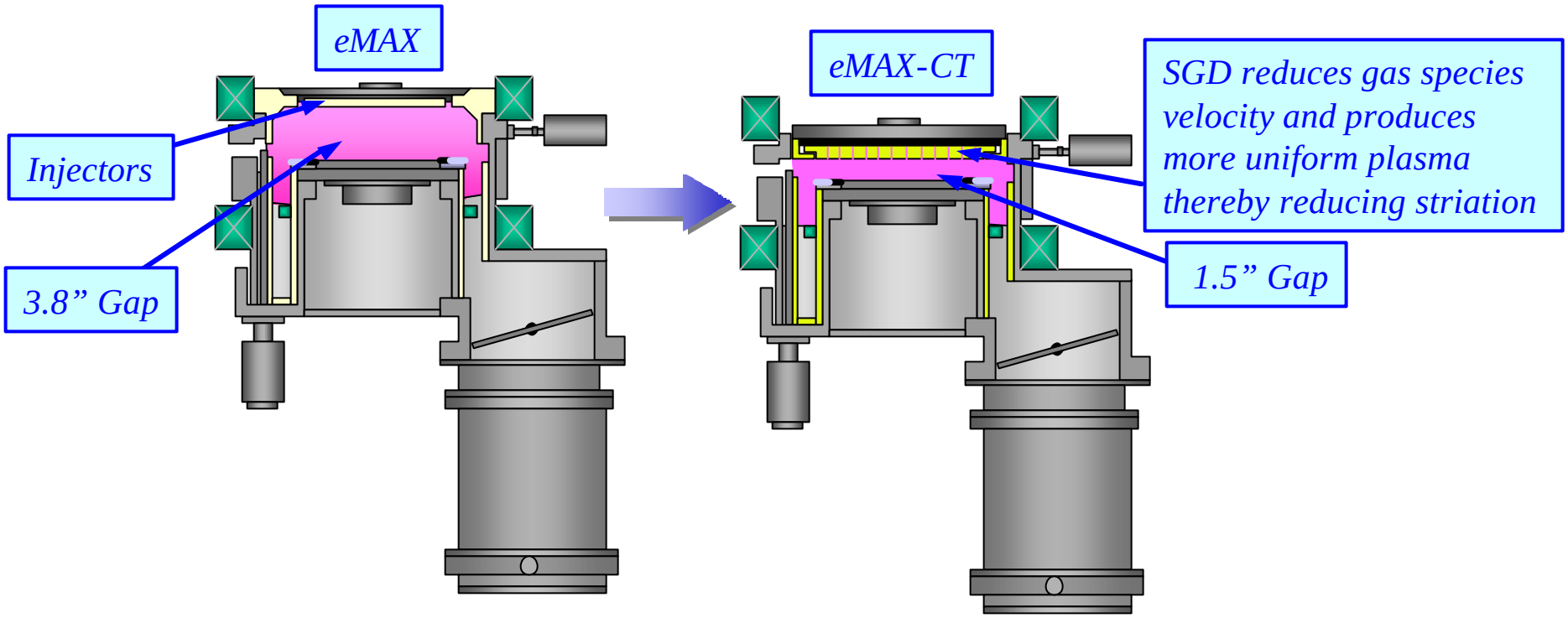
Striation Root Cause

- ***Directional bombardment by energetic ions: Vrf = f (B-field, pressure, RF power)***
- ***Insufficient sidewall polymer deposition: wafer temperature, C:F***



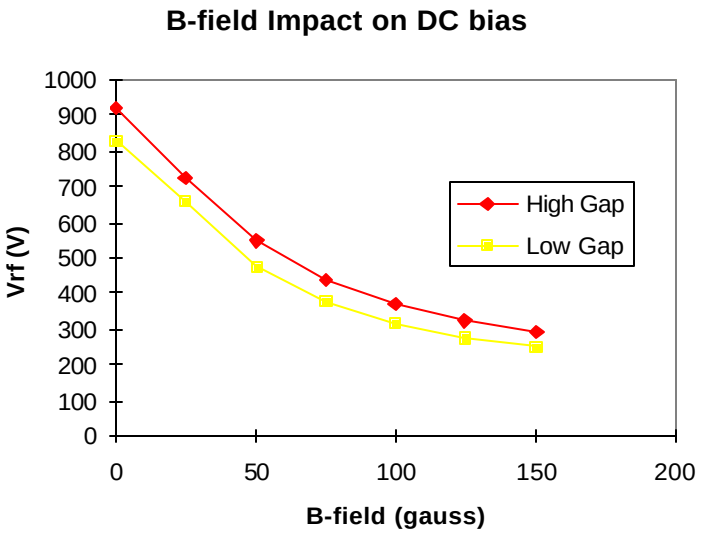


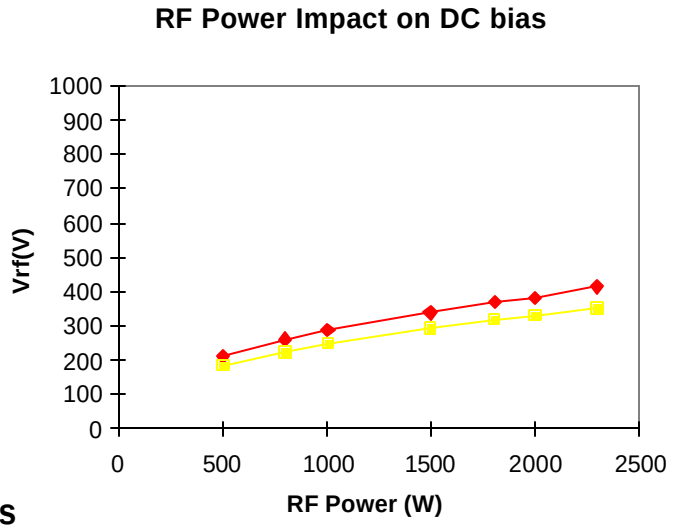
eMAX CIP: eMAX-CT

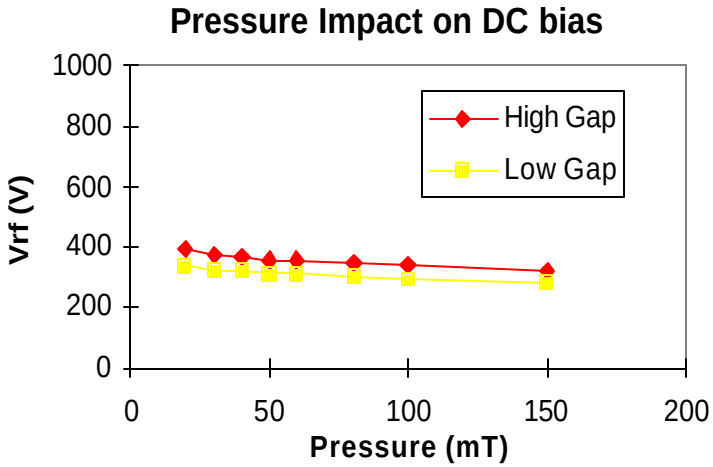


- 200mm CT adopted modifications from 300 mm CT hardware.
- 300mm CT intended for improving uniformity (narrow gap+RF delivery+ B-field+SGD)
- CT design also improves PR selectivity/Striation by employing narrow gap and SGD
- Cypress was the first customer for eMAX-CT 200 mm (Pre-a to manufacturing release).

Reduction of Vrf

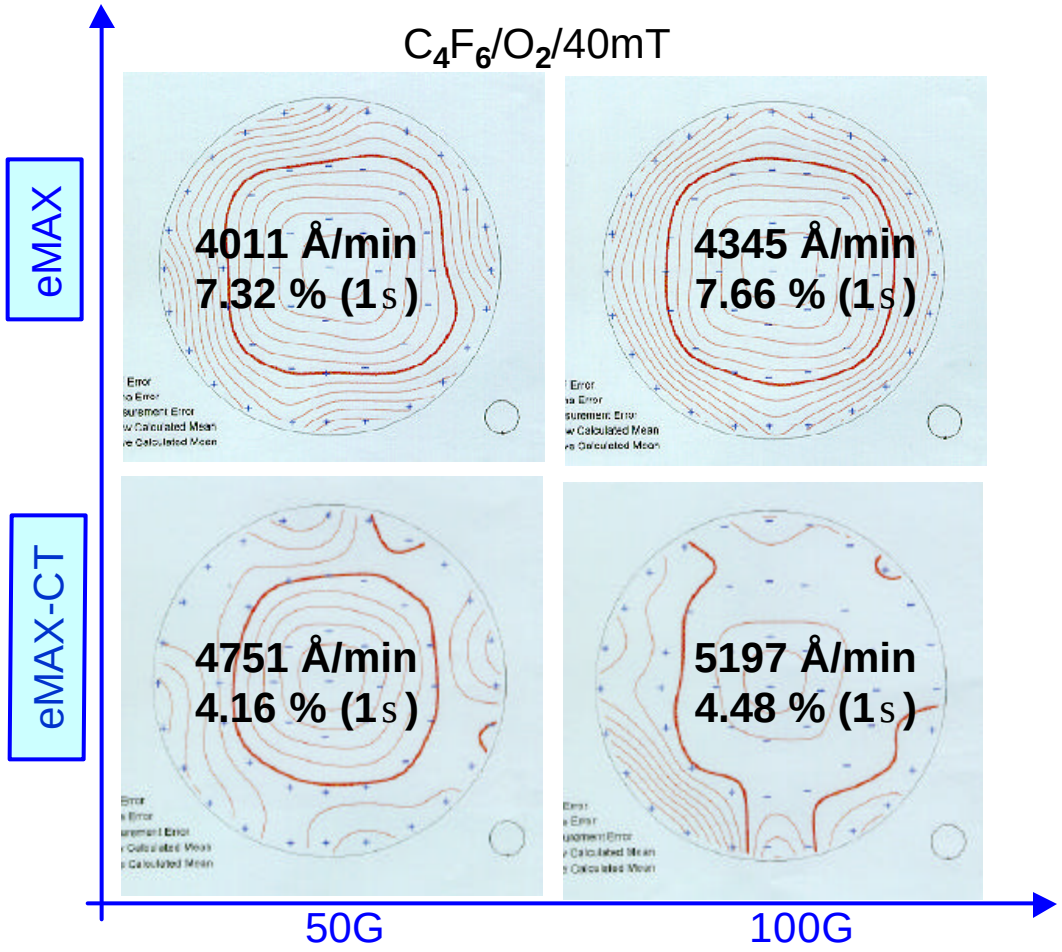






20V to 90V difference on Vrf is seen between eMAX (high gap) and eMAX-CT (low gap)

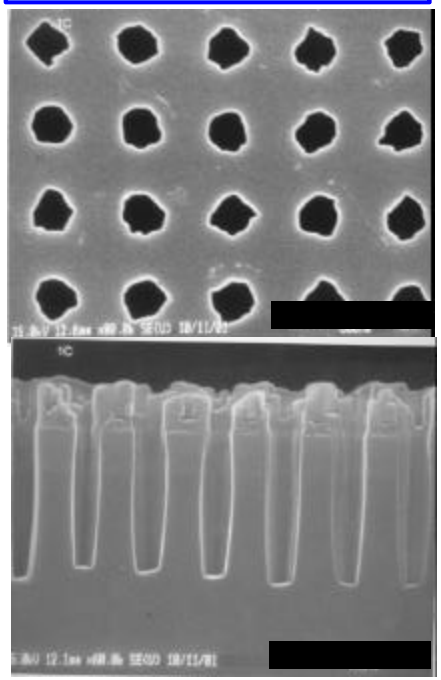
eMAX-CT: Process Characteristics



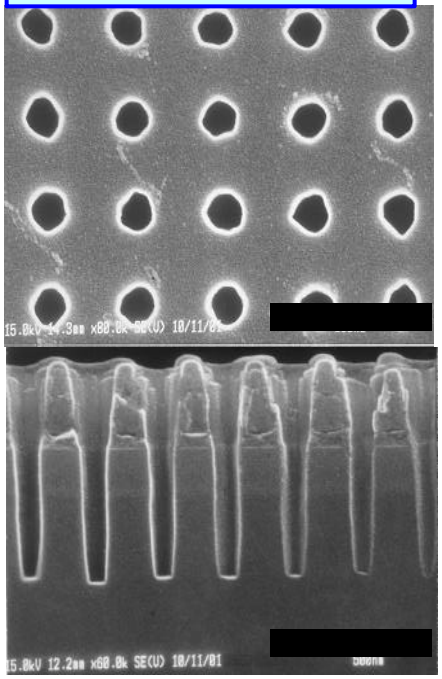
eMAX-CT simultaneously improves uniformity and etch rate

eMAX-CT: Process Characteristics

eMAX/C_4F_6-O_2/20 C

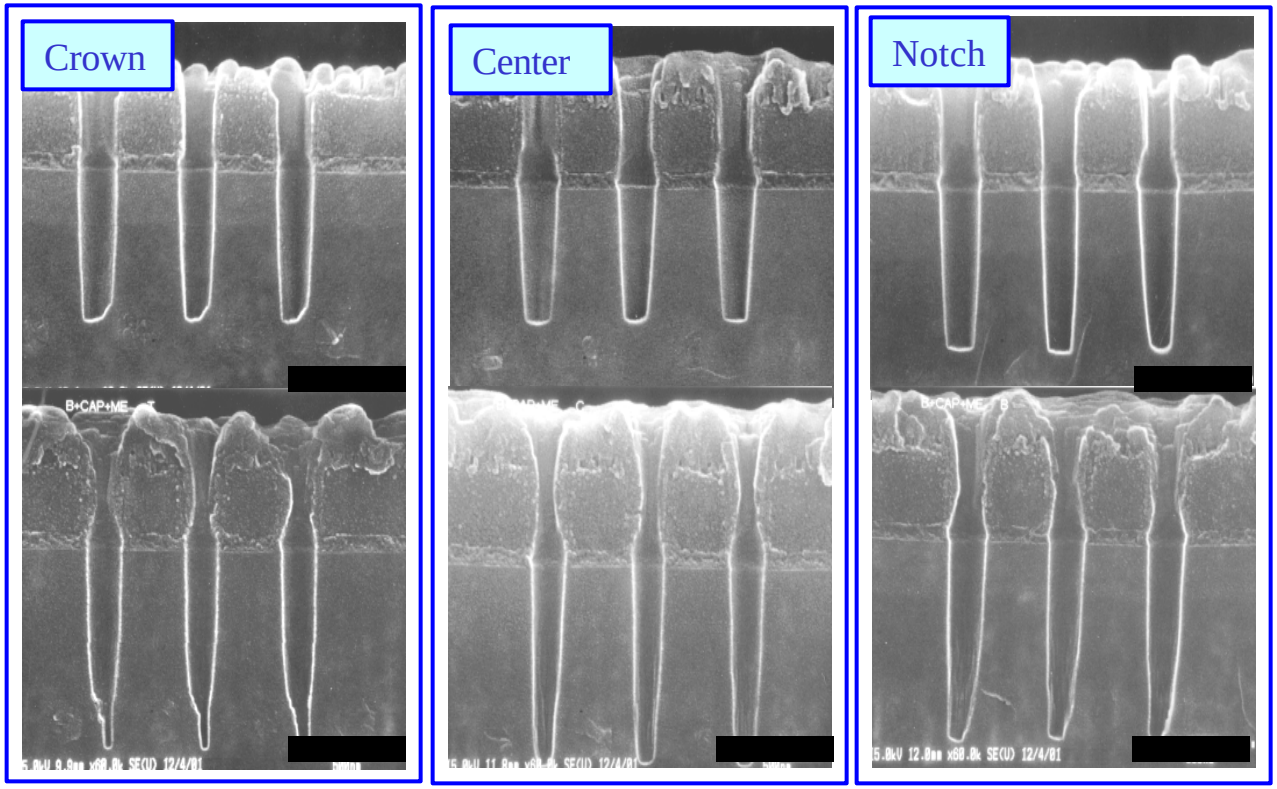


eMAX-CT/C_4F_6-O_2/20 C



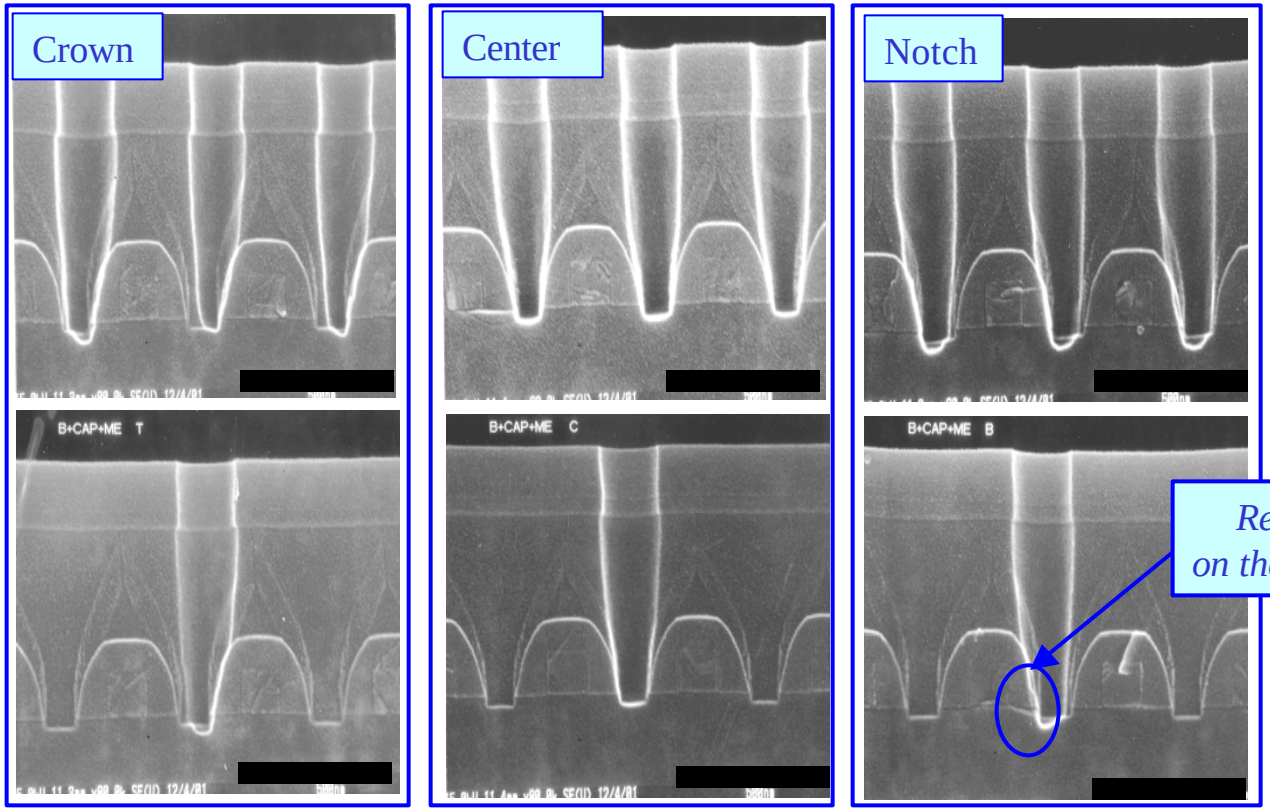
eMAX-CT improved P.R. selectivity and striation using C_4F_6-O_2 chemistry @ 20 C

eMAX-CT: Process Characteristics



Eliminated P.R. pinch off, acceptable profile, good within wafer uniformity

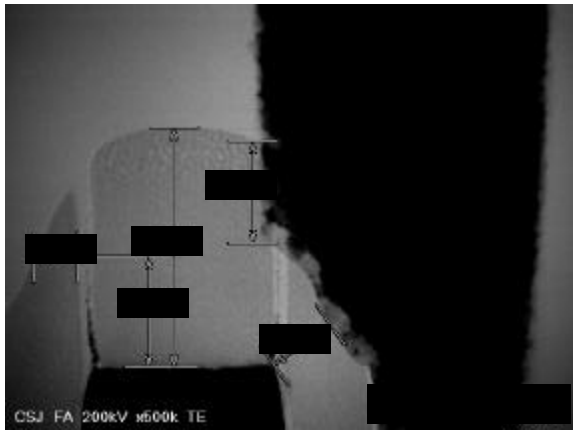
eMAX-CT: Process Characteristics

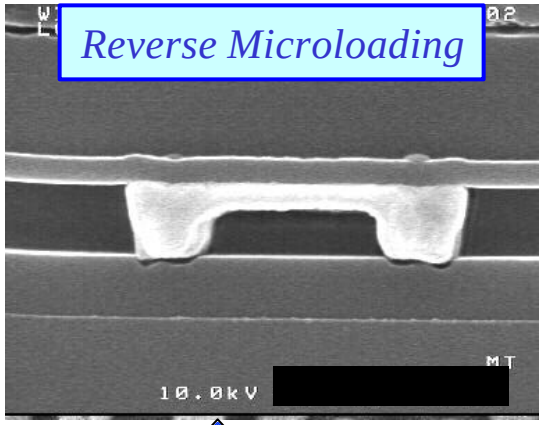


Process is selective to SiO_2 and Si_3N_4

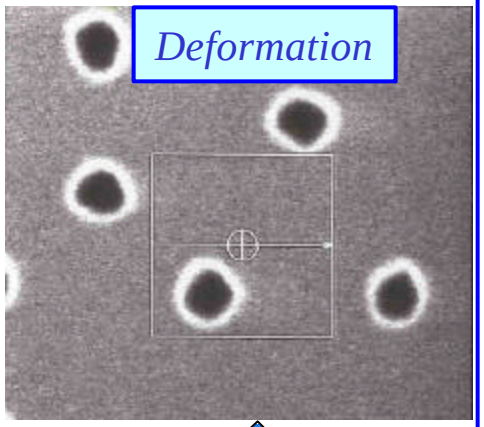
Some sensitivity to flower pattern and nonuniform SiO_2 gouge

Optimization Challenges





Reverse Microloading



Deformation

High +ve CD Bias

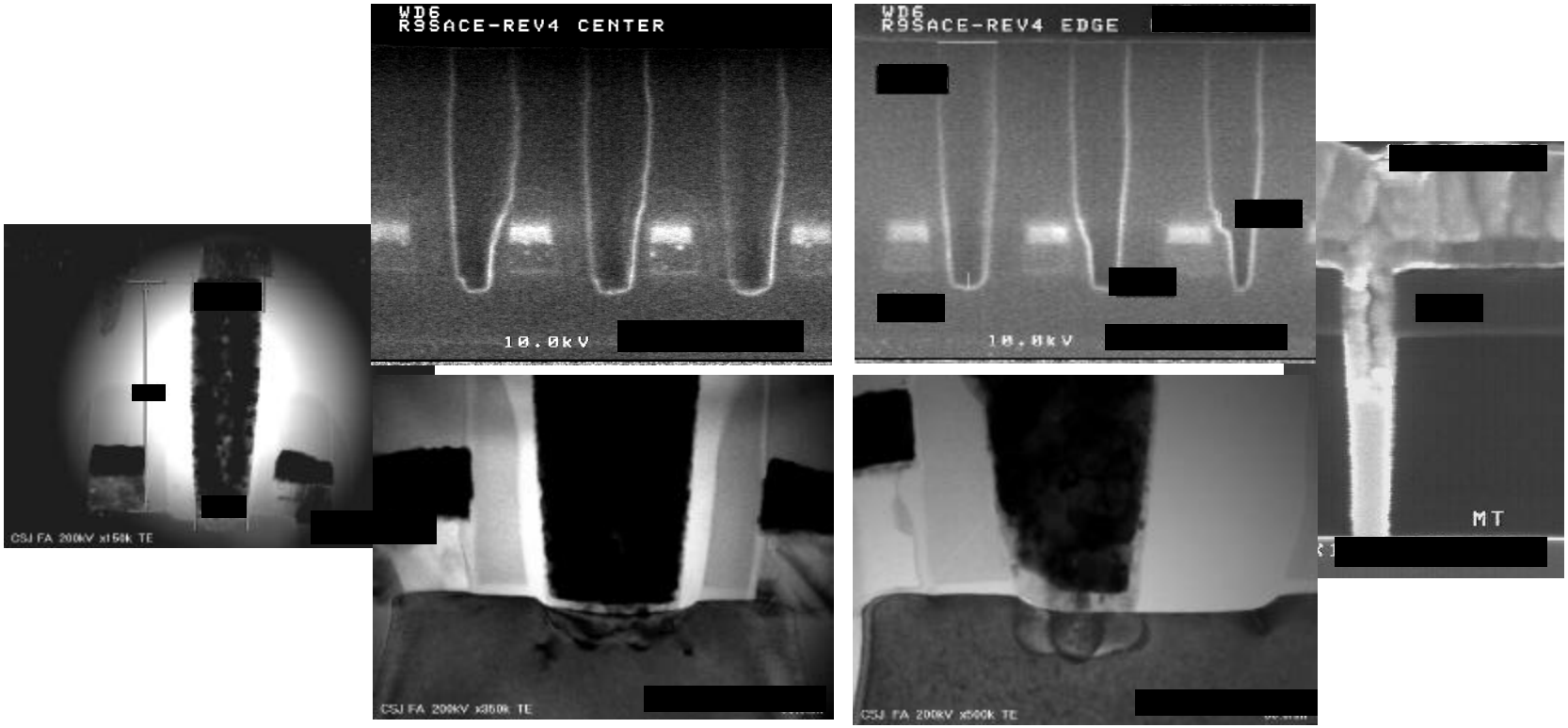
Striation

Trade off:

- *Contact deformation vs. CD bias/striation (ARCE)*
- *Etching open area vs. CD bias/striation (M.E. I)*
- *Si_3N_4/SiO_2 vs. Remaining PMD on spacer sidewall (M.E. II)*

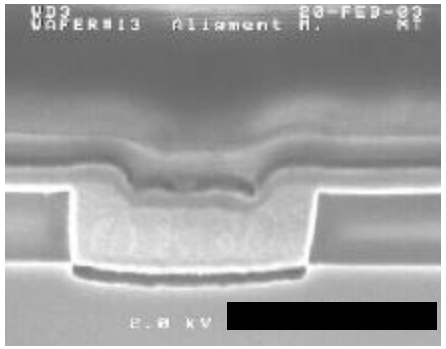
Required extensive optimization to develop a robust and manufacturable process

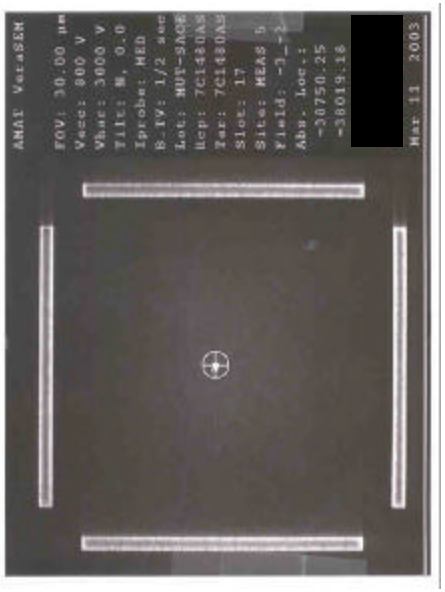
Optimized Process: Physical Verification

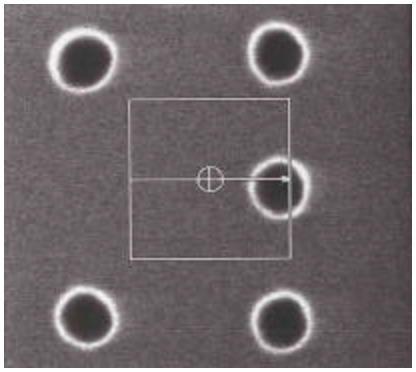


- *Eliminated remaining glass on spacer sidewall and improved landing profile by:*
  - *Optimizing transition from M.E. I to M.E. II*
  - *Optimizing B-field/RF power in M.E. II*
- *Verified process window over incoming variable limits (CD, thickness, etc…)*
- *Verified process performance over tool controllability limits.*

Optimized Process: Physical Verification

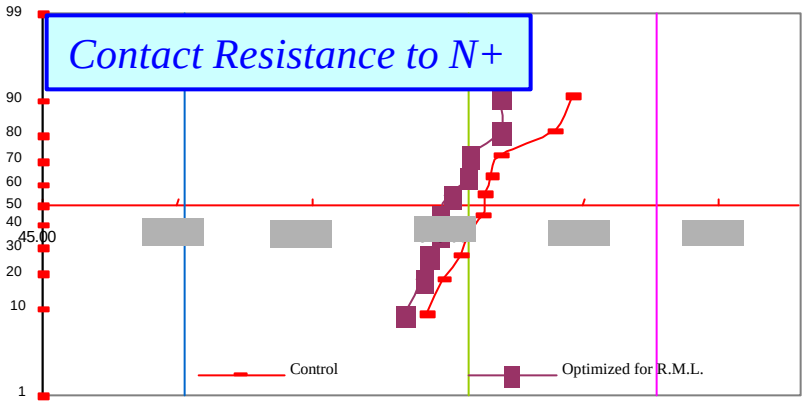


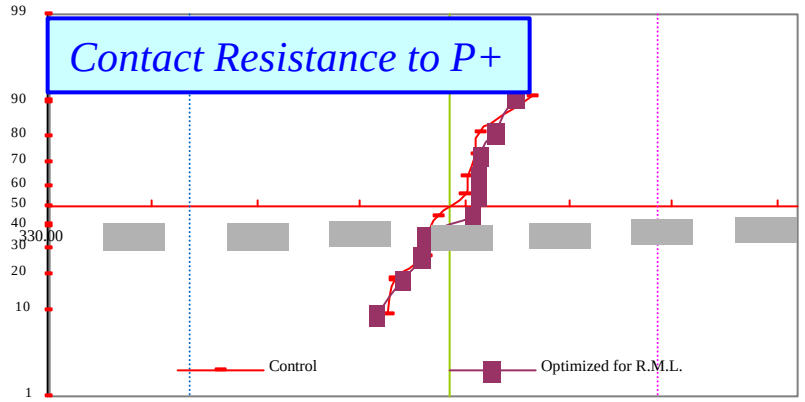


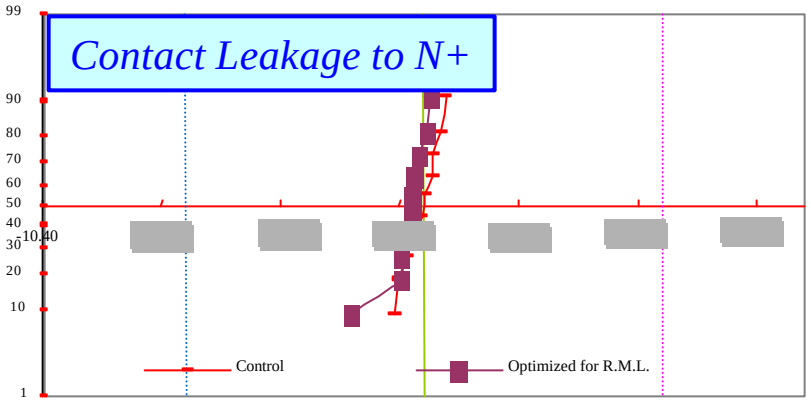


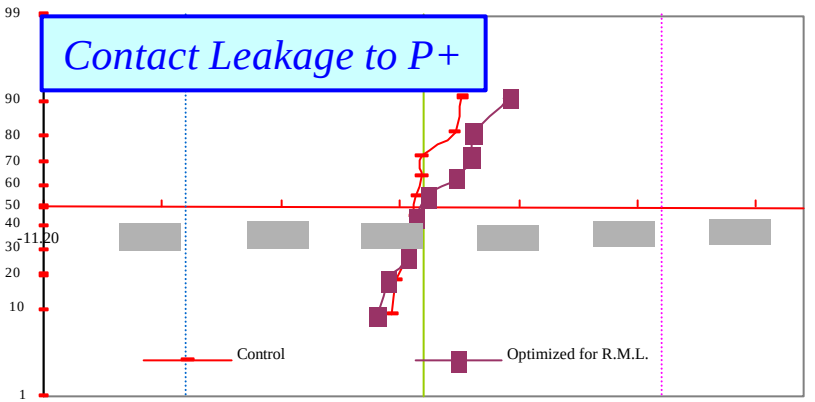
- *Reduced CD bias to allowable limit by TDR, etched overlay marks (1x20 um) and eliminated striation and contact deformation by:*
  - *Optimizing CHF_3/CF_4, RF power, B-field, and pressure in ARCE*
  - *Optimizing reactive gas/inert, C_4F_6/O_2, and wafer temperature (backside He pressure)*

Optimized Process: Electrical Verification









All critical electrical parameters are met and tightly controlled (high CpK/low Z) within EDR spec

Next Generation SAC Etch Challenges

- *More severe striation and higher CD bias for 70 nm and beyond due to thinner 193 nm P.R., tighter pitch, smaller CD and higher AR:*
  - *Require further reduction of Vdc/Vrf w/o affecting etch rate (dual frequency?)*
  - *Require robust ESC design to enable chucking at low RF powers/high backside He pressure (eliminate chucking instability => new ESC design)*
  - *May need to switch to inorganic BARC and/or alternative architecture*

- *Backside He cooling range with current ESC design will NOT be sufficient to independently control etch substeps temperatures:*
  - *Require more efficient cooling system*

- *Trade-off between profile and SiO_2 selectivity due to pitch reduction (flowers will pinch off!):*
  - *Move to different flow-pressure region (current tool capable?)*
  - *May require alternative architecture*

- *Chamber matching/process transfer/process mixing characterization become more critical:*
  - *More systematic efforts to address issues before transferring to manufacturing*

- *CD variation within wafer, wafer-to-wafer and lot-to-lot are approaching acceptable limits:*
  - *May require APC*

Summary

- *Completed qualification of eMAX-CT thru pre-a (prototype testing) to b–testing and manufacturing release.*
- *Developed a Rev 0 process on prototype HW to enable technology development.*
- *Optimized the process and eliminated all the captured failure modes.*
- *Verified process window over incoming variable and tool controllability limits.*
- *Verified electrical performance of final process.*
- *Successfully transferred process to manufacturing (Q2'03).*
- *Identified challenges for SAC etch on 70 nm technology node.*
- *Currently working with integration, CAD, design teams as well as AMAT dielectric etch division to appropriately address 70 nm requirements.*

Acknowledgement

- *We would like to thank:*
  - *Cypress manufacturing personnel (production and maintenance), integration and FA teams.*
  - *AMAT….*