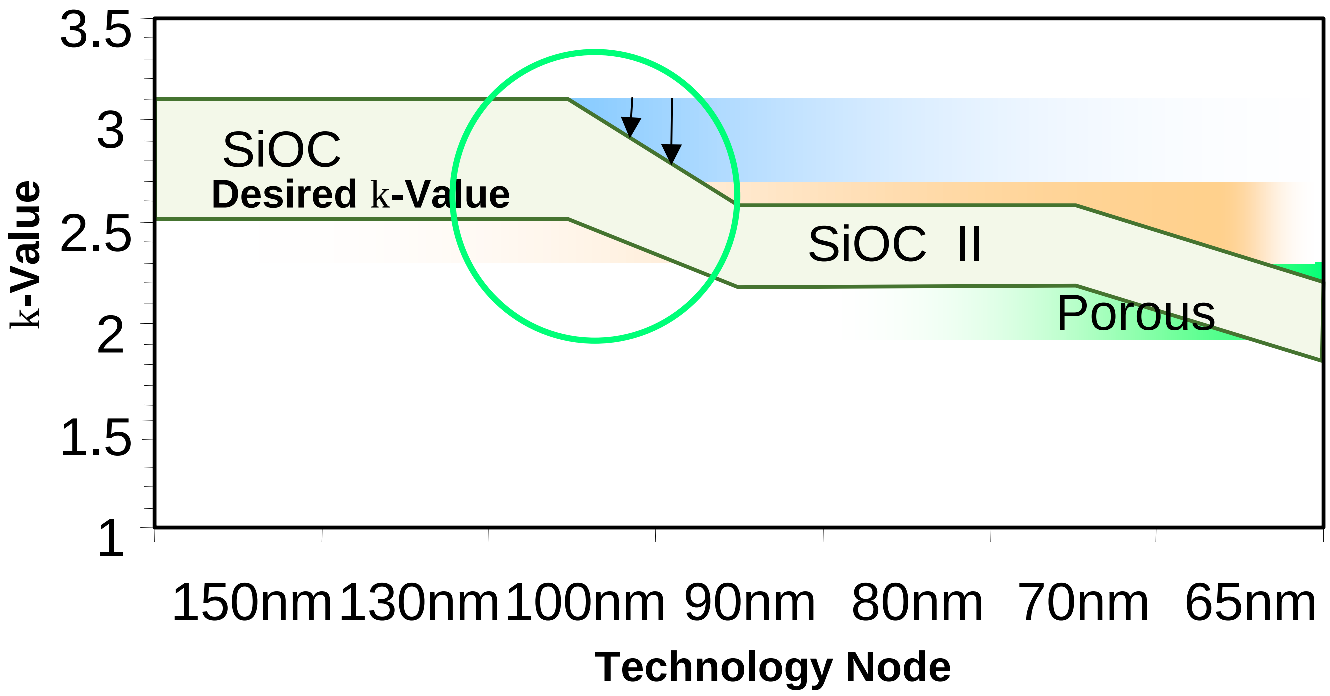
In-Situ Etch Depth Monitoring for Low-k Damascene Trench Etch

Dimitris Lymberopoulos, Ph.D.
Sr. Product Manager, Technical Marketing
Dielectric Etch Division
Applied Materials

Northern California Chapter and the American Vacuum Society
Plasma Etch Users Group Meeting
April, 2002

Low-k Dielectric Implementation

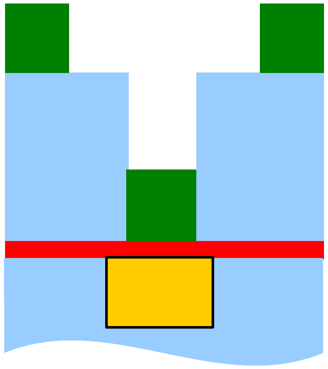


- ITRS roadmap calls for reduction in as-deposited film κ-value (material issue) and effective κ -value (process and integration issue)
- At 100nm, the budget for effective κ-value vs. today's materials shrinks
- eMAX™ EnTek™ offers etch processing with minimum impact to effective κ-value
  - No κ-value change of bulk film
  - Enable elimination of higher κ middle stop layer

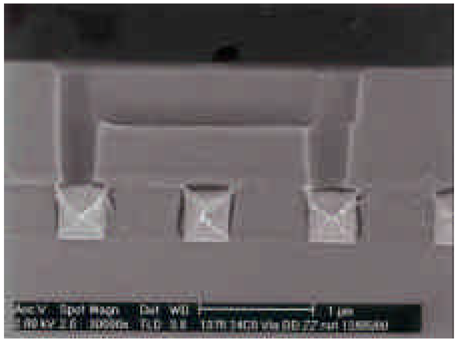
Source: ITRS, 2001

Challenges of Low-κ Dual Damascene Etching

- Middle Stop Layer
  - Increases the number of processing steps and complexity for dual damascene.
  - Increases the effective κ-value of the interconnect by 10%, slowing device speed.
- Stripping Induced κ-Value Shift
  - Stripping the photoresist over a low-κ stack can result in κ -value shift.



Trench Litho

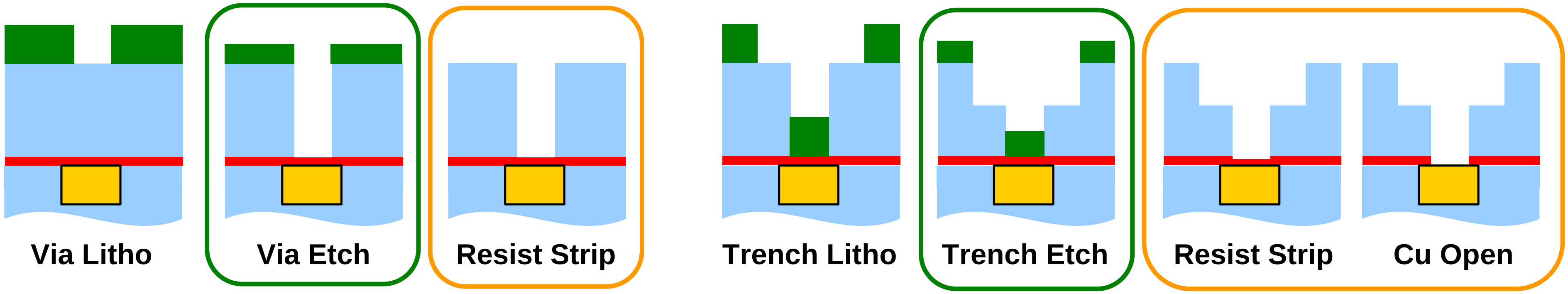


Post Trench Etch
Ash/BloK Open
2 in 1 Process

- Fluorine Memory Effect
  - Use of single chamber concept can result in Fluorine containing polymer deposits in the chamber (Fluorine memory effect) leading to damage of feature profiles.
- Selectivity to the Bottom Stop Layer
  - Non-uniform etch selectivity across the wafer or between small and large features (microloading) can result in punch-through of the stop layer and sputtering of copper onto the wafer and chamber.

Dielectric Etch eMAX EnTek Centura

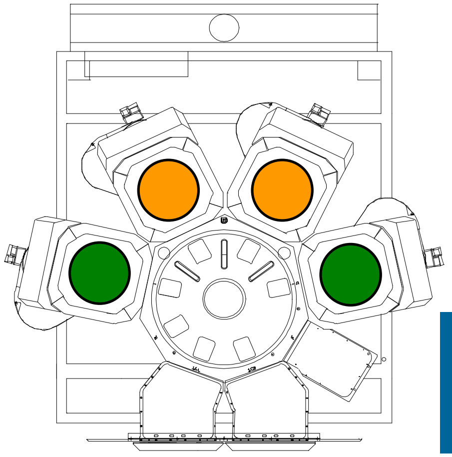
Optimized/Cost-Effective Approach



☐ **eMAX EnTek Chambers configured for “Deposition Mode” processes**

☐ **eMAX EnTek Chambers configured for “Clean Mode” process**

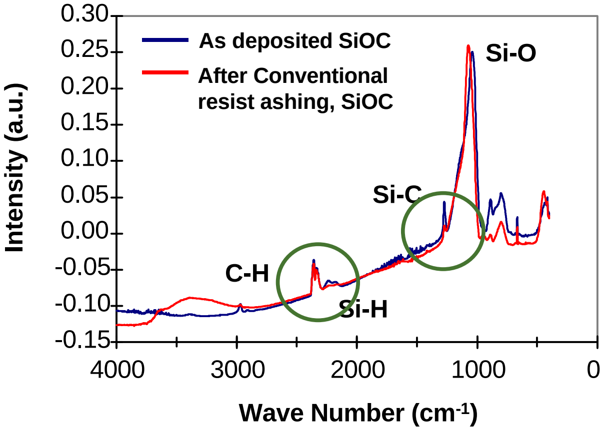
- **Separate Deposition Mode and Clean Mode processes on the same platform**
  - Eliminate Fluorine memory effect
  - Superior selectivity to SiN, SiC barrier
  - High fidelity pattern transfer (low-κ profile, and CD control)
- **Enabling Sensor Technology**
  - In-situ trench depth control
  - Eliminate middle stop layer reliably for production

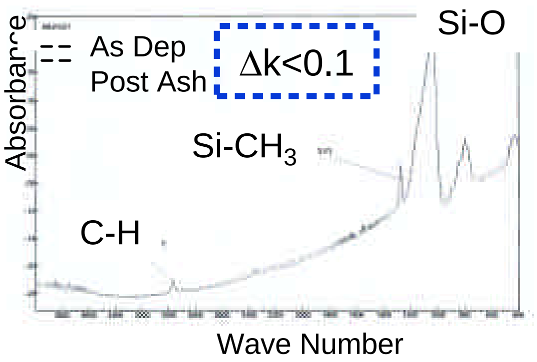


Separating Deposition™ and Clean Mode™ Etch Processes Provides an Optimized Pathway for Low-k Integration

eMAX EnTek Integrated Strip Process

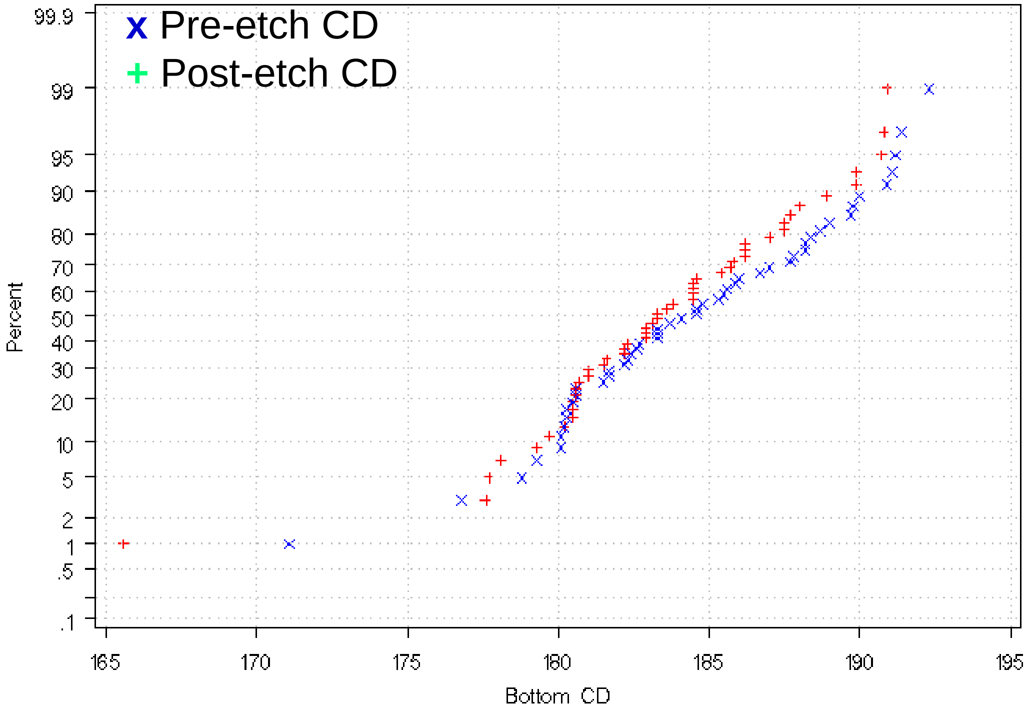
Impact on k-value

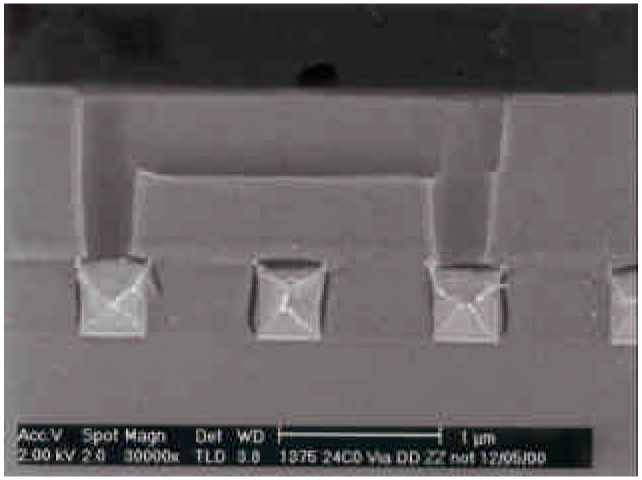




FTIR Indicates no Significant Structure Changes after Etch and Strip

eMAX EnTek Critical Dimension Control





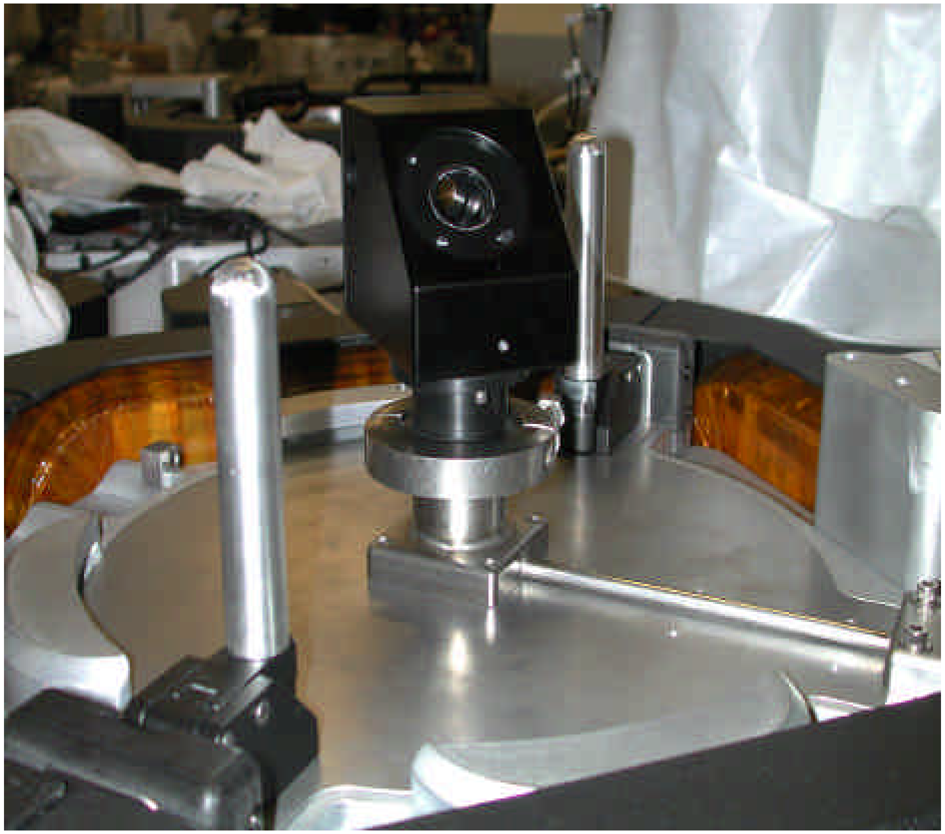
Post Trench Etch
Ash/BloK Open
2 in 1 Process

Trench Etch CD Bias (Bottom): < 1nm

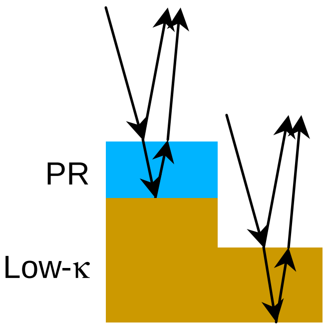
eMAX EnTek Maintains Critical Dimension Integrity for Stable Linewidth Control

*i*RM, Chamber Interface

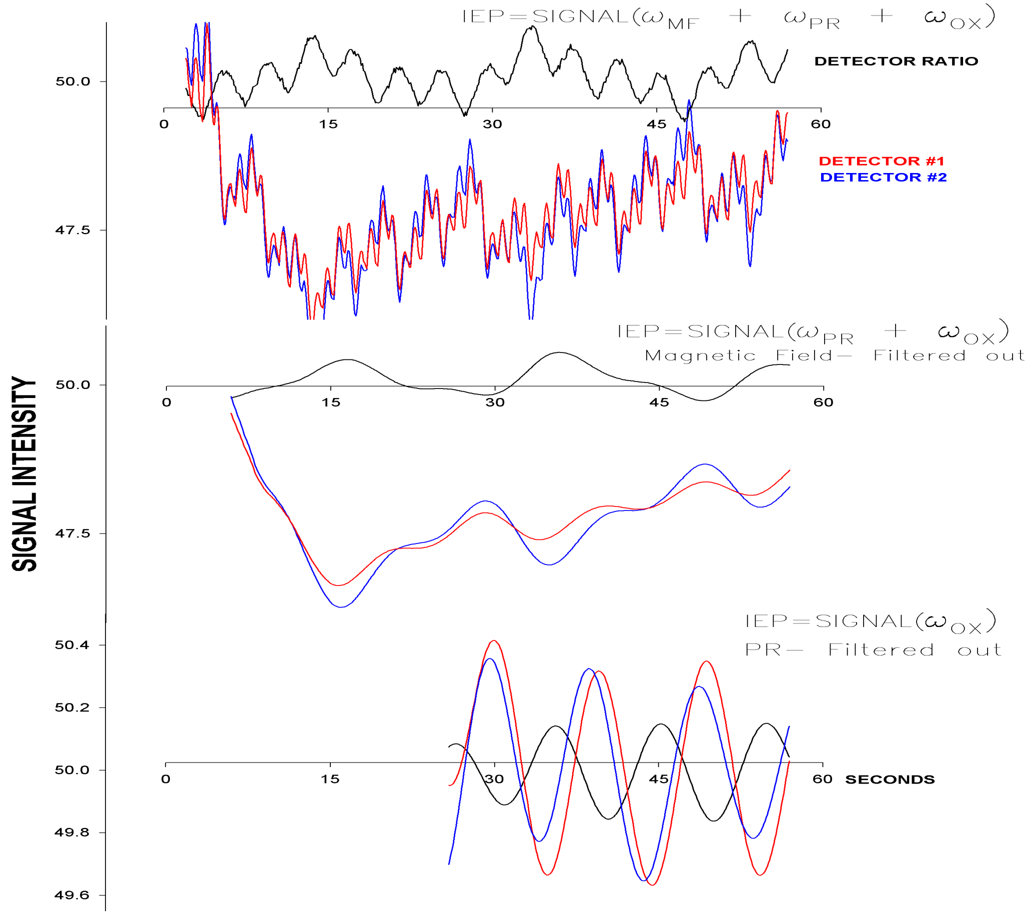
Sensor/Controller Assembly



*i*RM, Traces

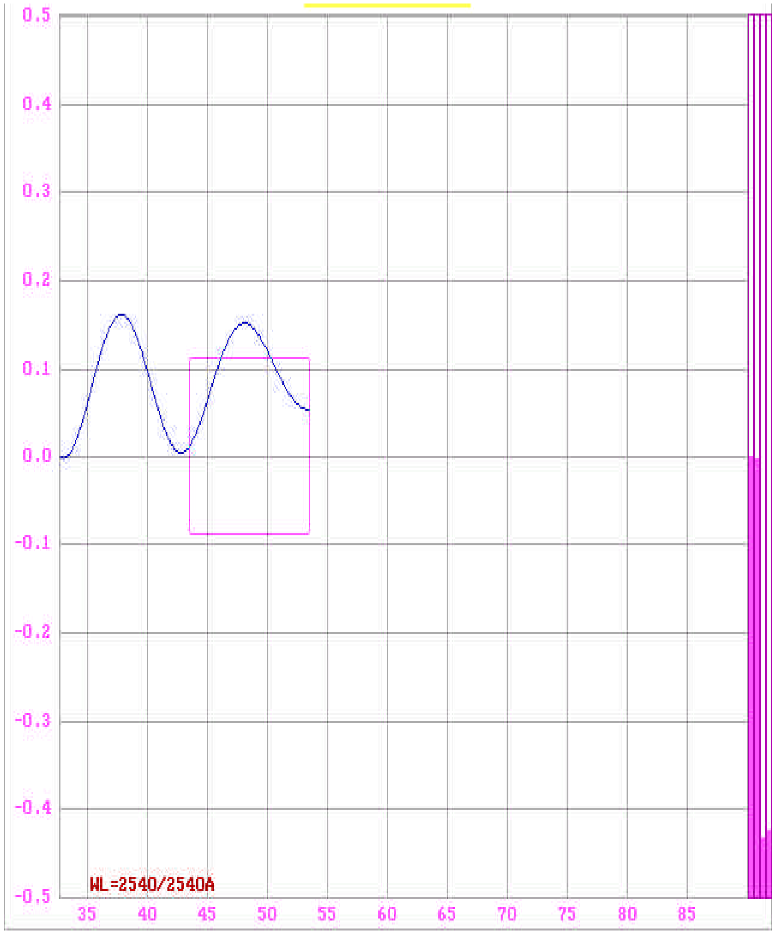


Pattern wafers produce interferometric signals that contain multiple frequency components.

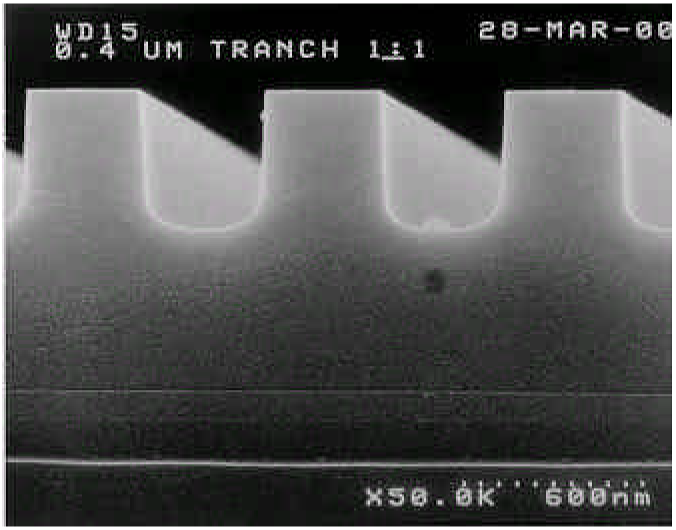


- Digital Signal Processing (DSP) using various real-time filters are used to average out the magnetic field and separate the undesired photoresist signal from the dielectric film signal.
- The real time signal consisting of three frequencies originating from the photoresist (ω_{pr}), dielectric film (ω_{ox}), and the magnetic field modulation (ω_{mag}).
- The filtered signal with the contribution from the magnetic field removed.
- The signal attributed to the dielectric film signal remaining after the removal of the photoresist contribution.

Damascene Trench Etch
PECVD TEOS



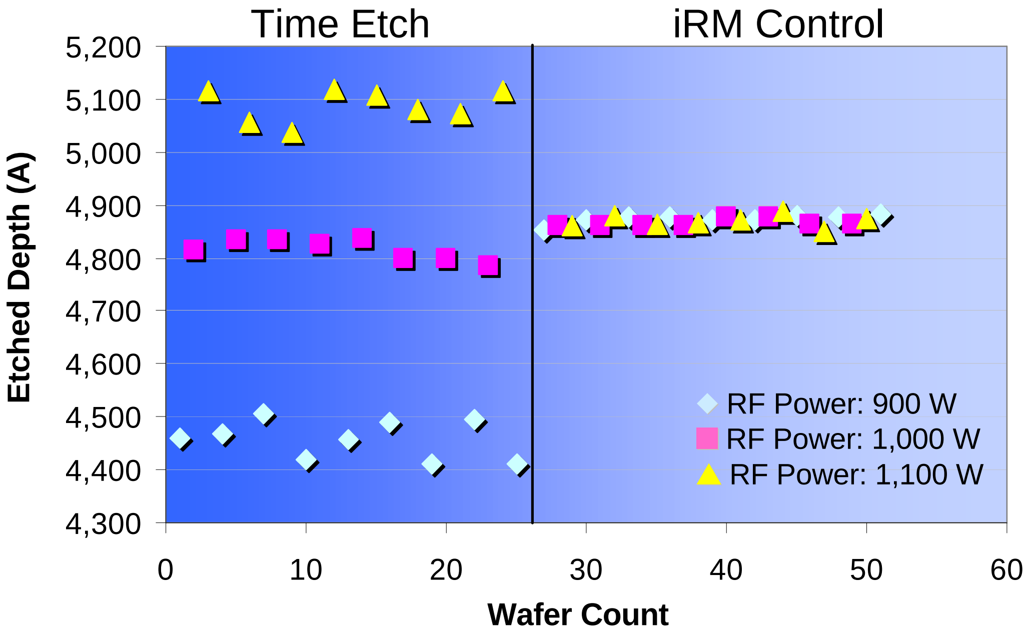
Open Oxide Area: 50%
Film Structure: $1\mu m$ Ox / $0.1\mu m$ Nitride / $1\mu m$ Ox
Etch Depth: $0.46\ \mu m$ (SEM)
Feature size: $0.4\ \mu m$



Predicted Etch Depth (iRM) = 0.46 mm, Etch Depth (SEM) = 0.46 mm

Tighter Etched Depth Control Using iRM

Blanket SiO2 on Si

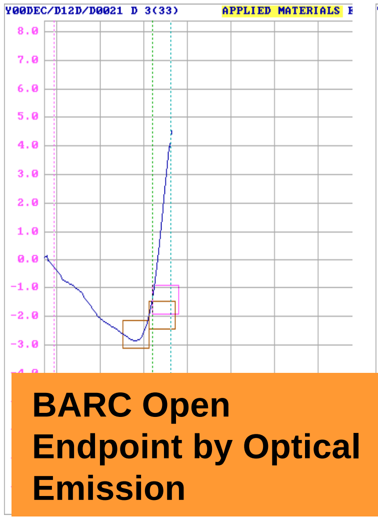


- iRM enables precise etch depth control by compensating for etch rate variations.
- The RF power was deliberately varied within +/- 10% of the setpoint of 1000W while etching a simple stack of blanket SiO2 on Si.
  - The RF power variation (900-1100 W) naturally had an impact on the etch rate and etch depth for a timed process (59 s, based on the setpoint of 1000W)
  - The same RF power variation was applied while the process was under controlled by iRM; although the wafers were subject to the same variation in etch rate, the etch depth was tightly controlled

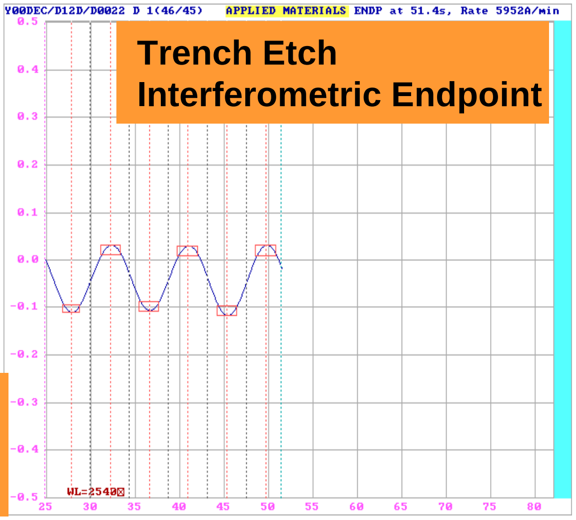
Note: the depth measurement data is obtained using Nanometrics 8300

iRM Interferometric Endpoint Sensor

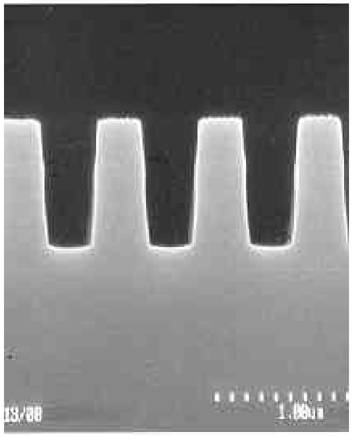
for Etch to Depth Control



BARC Open Endpoint by Optical Emission

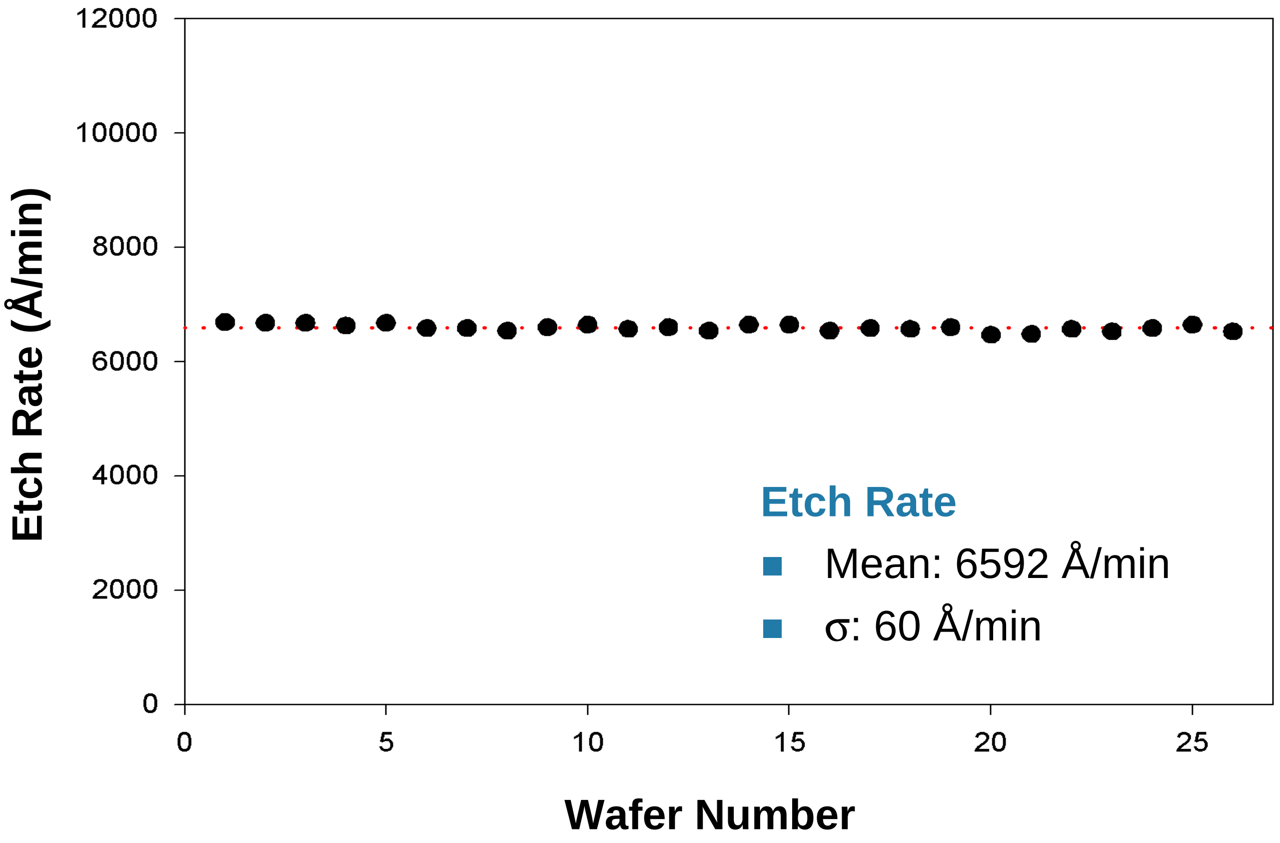


Trench Etch Interferometric Endpoint



- The combined use of Optical Emission (OE) and iRM can offer an accurate control of depth.
- The detection of BARC open can be used to trigger iRM.
- The combined solution delivers repeatable BD etch-to-depth results regardless of incoming BARC thickness variation.

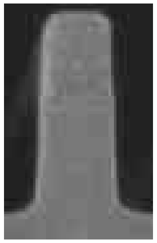
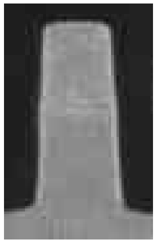
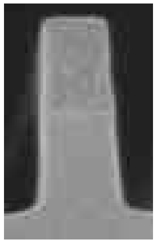
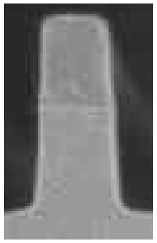
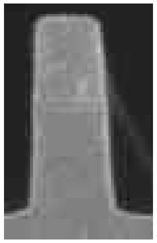
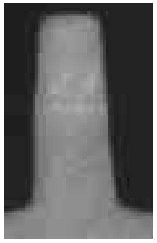
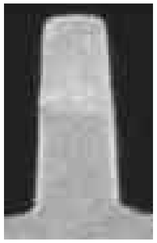
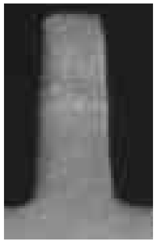
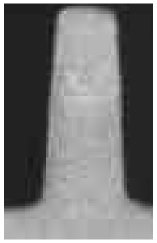
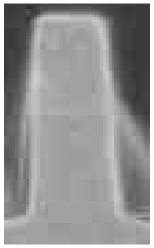
*i*RM Data from Checkerboard Lot



Etch Rate

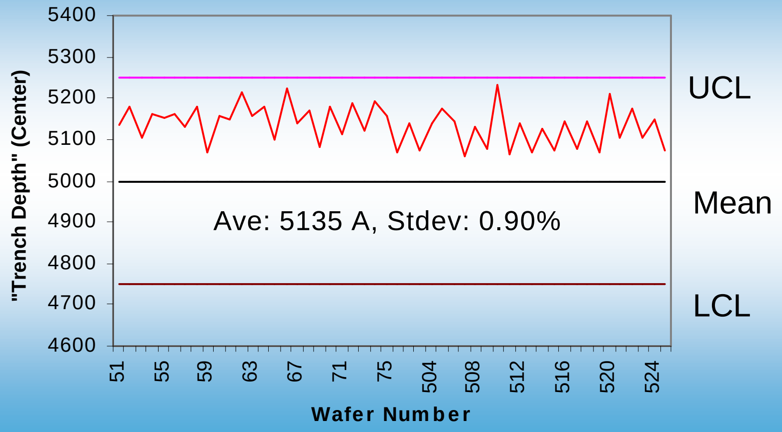
- Mean: 6592 Å/min
- σ: 60 Å/min

eMAX EnTek Dual Damascene Trench Burn-in

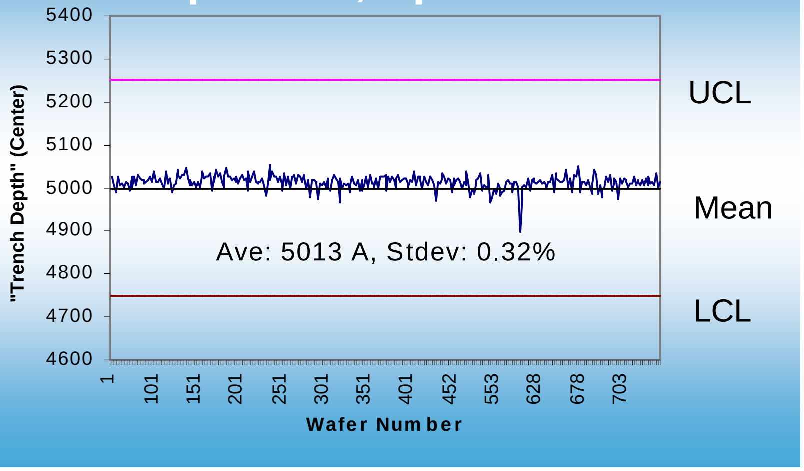
Wafer #	**25**	**150**	**400**	**625**	**1060**	**1275**	**1600**	**1865**	**2100**	**Wet clean**
Center										
Etch depth: to Trench Bottom		**4380 Å**	**4416 Å**	**4480 Å**	**4545 Å**	**4545 Å**	**4545 Å**	**4450 Å**	**4710 Å**	
iRM		**4390 Å**	**4350 Å**	**4560 Å**	**4440 Å**	**4420 Å**	**4470 Å**	**4340 Å**	**4730 Å**	

Low-k Dep/Etch Process Module™

Trench Depth



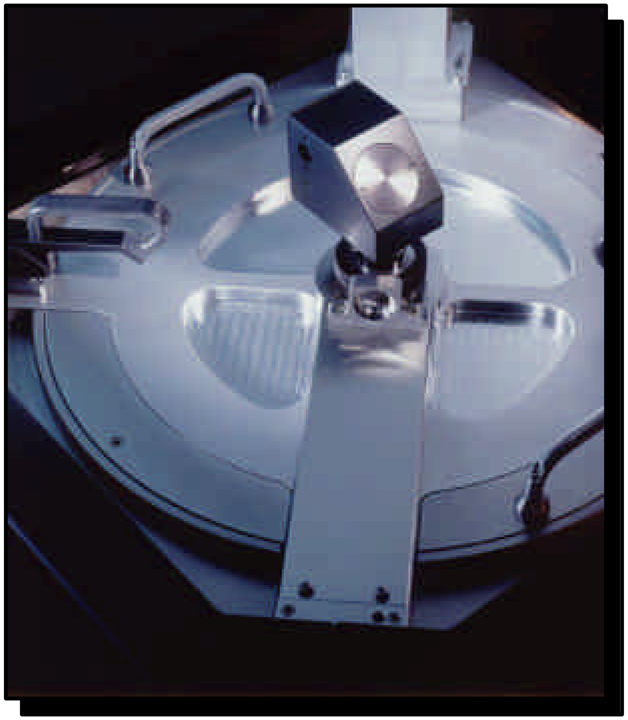
Trench Etch (Open Loop)
Cp = 1.80, Cpk = 0.83



Trench Etch iRM Control
Cp = 5.19, Cpk = 4.92

iRM control provides a 3X improvement in C_p and 6X improvement in C_{pk}

Summary



- iRM is an in-situ interferometric endpoint detector that enables:
  - Reliable damascene trench depth control by compensating for incoming thickness variation and process drifts.
  - Elimination of middle-stop layer that help extend proven ILD materials to next device generation.
  - Production-worthy, wafer-to-wafer trench depth repeatabiliy for structures with no middle-stop-layer.

ACKNOWLEDGEMENTS

Zhifeng Sui

Coriolan Frum

Hongching Shan

REFERENCE

Integrated Process Control Using In-Situ Sensor for Etch,
Solid State Technology, April 2002

APPLIED MATERIALS®