Process Diagnostics and Control Group

Roughness Metrology
The next Dimension

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Agenda

- Challenges in Roughness Metrology
- Roughness Metrology Requirements
- Suggested Approach for Roughness Measurement
- Line Roughness Definitions
  - Line Edge Roughness (LER)
  - Line Width Roughness (LWR)
  - Autocorrelation
  - Case Study
- Contact Edge Roughness (CER)
  - Definitions
  - Case Study
- Summary

Line Roughness Key Metrology Challenges
(CD-SEM Perspective)

- SEM resolution for clear identification of edge roughness
- Measurement accuracy to enable the separation of roughness attributes from SEM artifacts (charging)
- Ability to differentiate SEM noise from real roughness
- All above over sensitive resists and other advanced materials

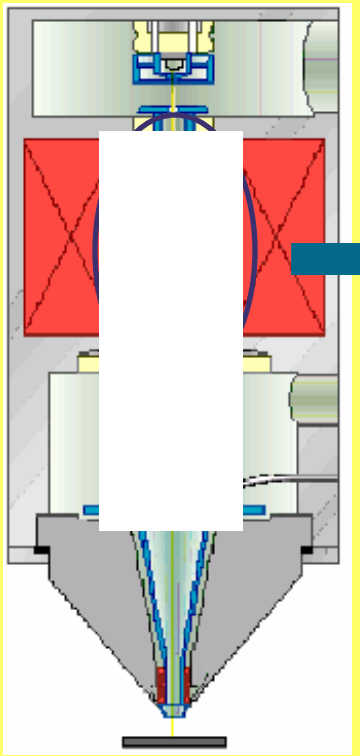
ITRS Roughness Requirements

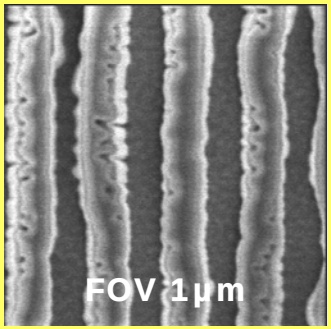
- LER – Local line width variation (3σ total, all frequency components included, both edges)
- LWR for non correlated line edge roughness LWR = √2*LER
- LER control
  - 90nm – 3 nm
  - 65nm – 2 nm
- LER Precision (P/T=0.2)
  - 90nm – 0.6nm
  - 65nm – 0.4nm
- Measurement tool performance needs to be independent of target shape, material, and density

Year of Production	*2003*	*2004*	*2005*	*2006*	*2007*	*2008*	*2009*
Technology Node		*hp90*			*hp65*		
DRAM ½ Pitch (nm)	*100*	*90*	*80*	*70*	*65*	*57*	*50*
Wafer CD metrology tool precision (nm) * (P/T=.2) for LWR***	0.7	0.6	0.5	0.4	0.4	0.4	0.3
Line width roughness (nm, 3 σ) <8% of CD ***	3.6	3	2.6	2.2	2	1.8	1.6

Introduction to Edge Roughness Solutions

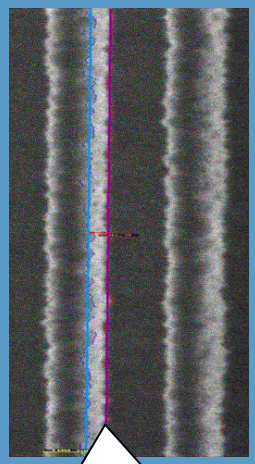
VeritySEM Technology

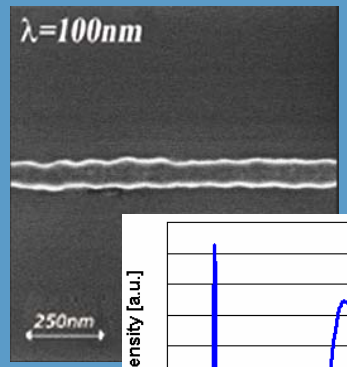


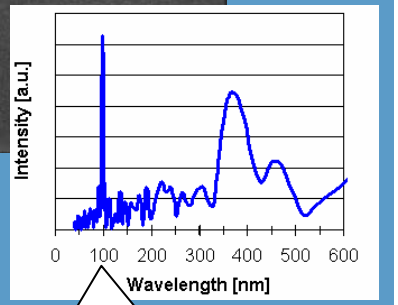


High resolution & low distortion in large field-of-view scanning

LER/LWR Characterization







Roughness in tilt for discriminating bottom roughness

Wavelength analysis

Enabling edge roughness based process control

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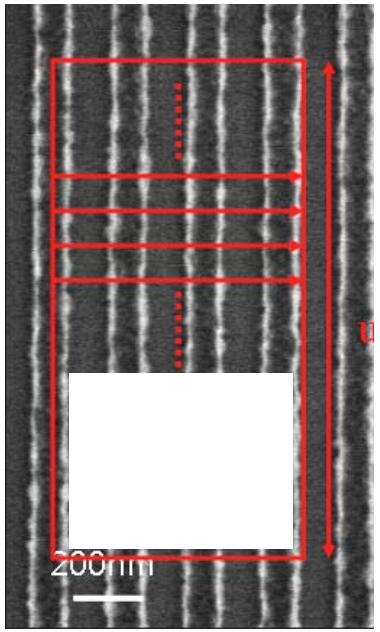
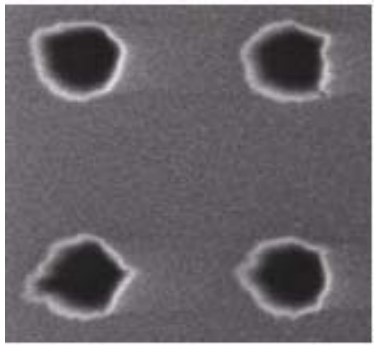
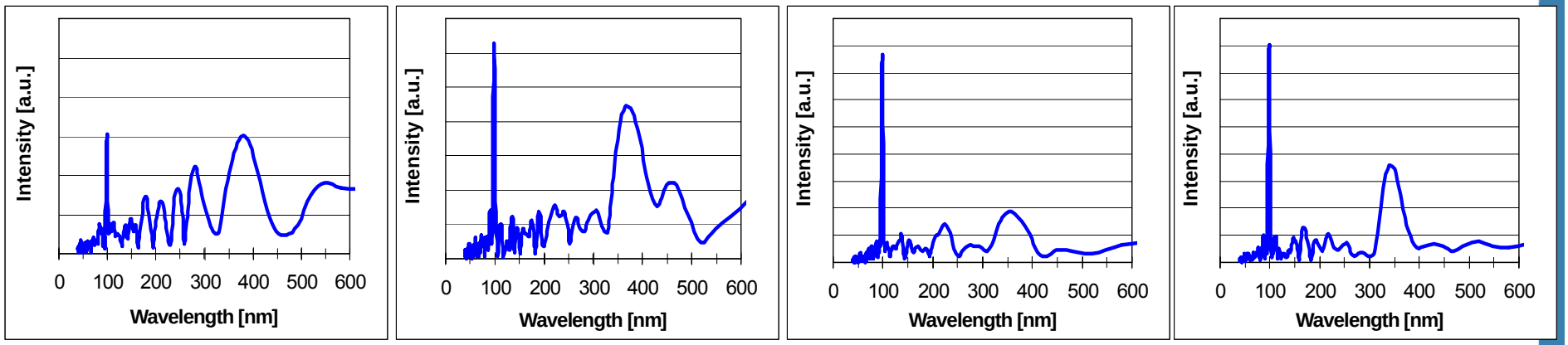
VeritySEM Approach for Roughness Measurement

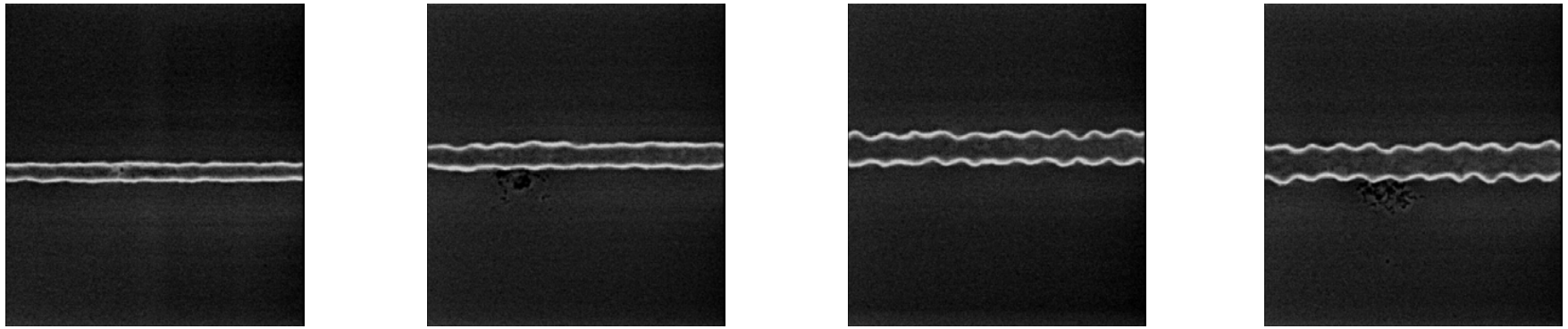
- **Line and Contact Roughness should be measured with the following recommended conditions**
  - Long Measurement Box of 20 times the technology node or fit several CH in single analysis
  - Small pixel size for High resolution in scan direction and edge direction for optimal roughness curvature identification
  - MacroCD analysis of Large Number of adjacent edges in order to improve statistic validity
  - Frequency range filtering to screen high frequency (noise) and low frequency (3 times the technology node)





Spatial Frequency: High Sensitivity to Amplitude



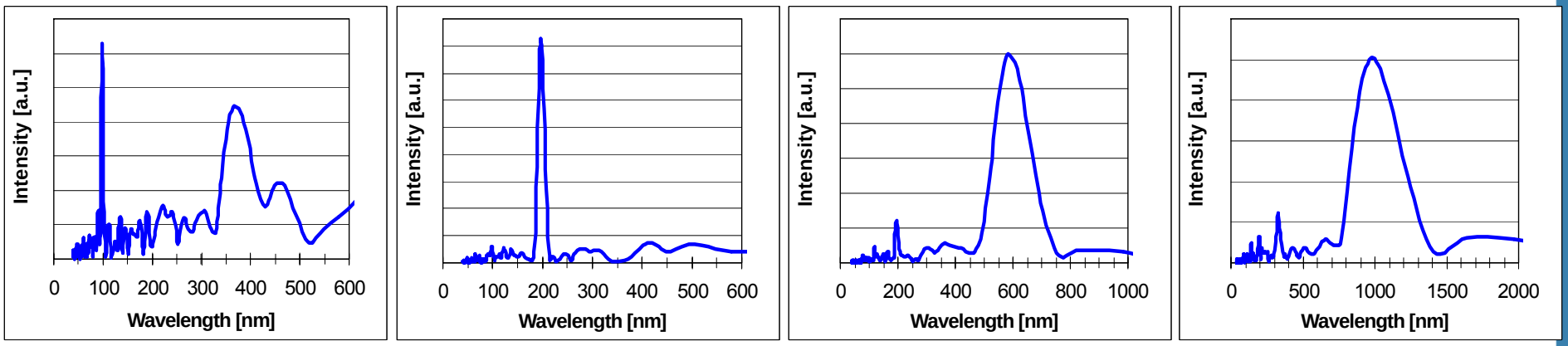


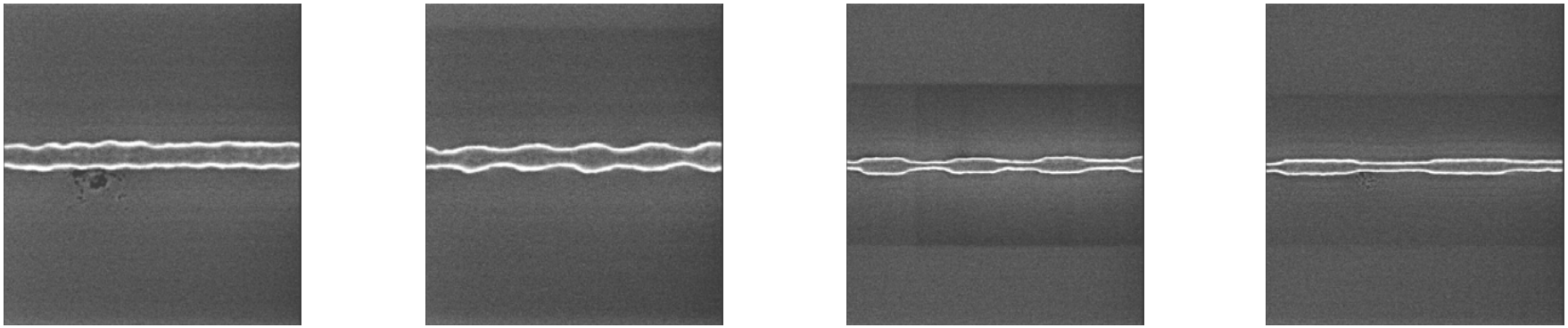
20nm 50nm 80nm 100nm

nominal amplitude (nominal periodicity constant at 100nm)
detection of main frequency even for small LER (down to 5nm)

Thomas Marchner,
Infineon SPIE 2003

Spatial Frequency: High sensitivity to Frequency





100nm 200nm 600nm 1000nm

nominal periodicity (nominal amplitude constant at 50nm) shift of peak position increase of line-width of main peak as expected theoretically

Infineon, SPIE 2003

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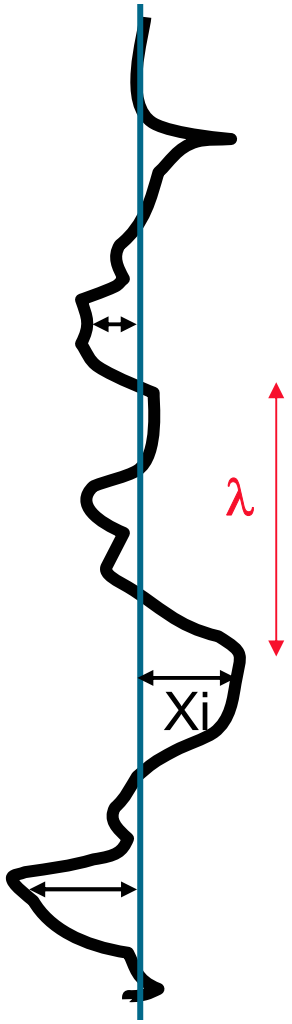
LER Precision



$$LER = 3 \times \sqrt{\frac{\sum_{i=1}^{n} (X_i - \hat{X}_i)^2}{n-2}}$$

	LER [nm]	3 sigma LER [nm]
110nm L/S Litho	8.8	0.65
110nm L/S Etch	5	0.3
Intentional LER Amplitude / Periodicity		
20nm / 100nm	6.4	0.39
50nm / 100nm	9.2	0.32
130nm / 100nm	27.8	0.43
50nm / 200nm	20	0.14
50nm / 600nm	27.8	0.49

Roughness Precision < 0.5nm
Meeting 70nm Requirements

Infineon, SPIE 2003

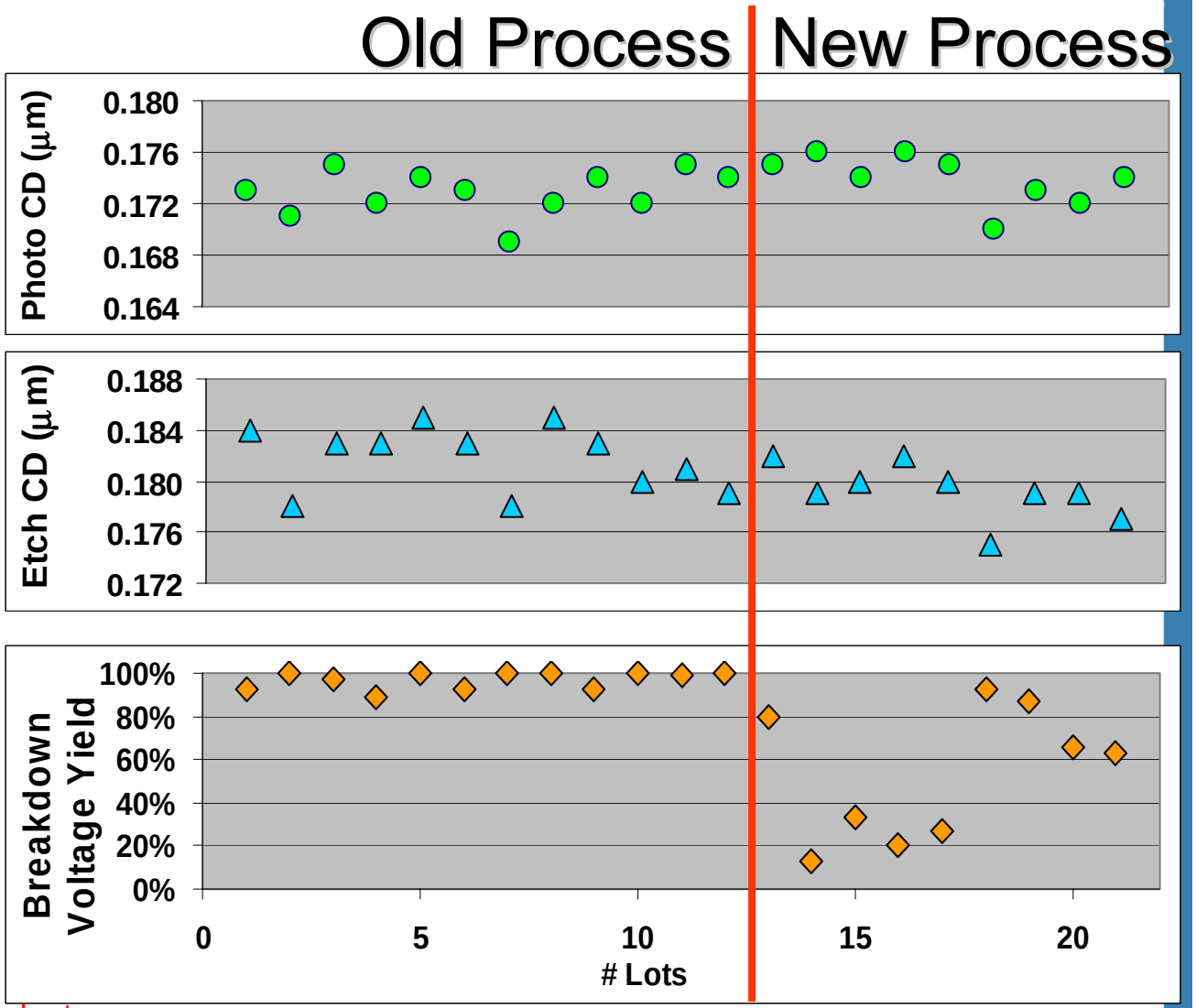
CER Introduction

Slide Removed

Contact Process Change

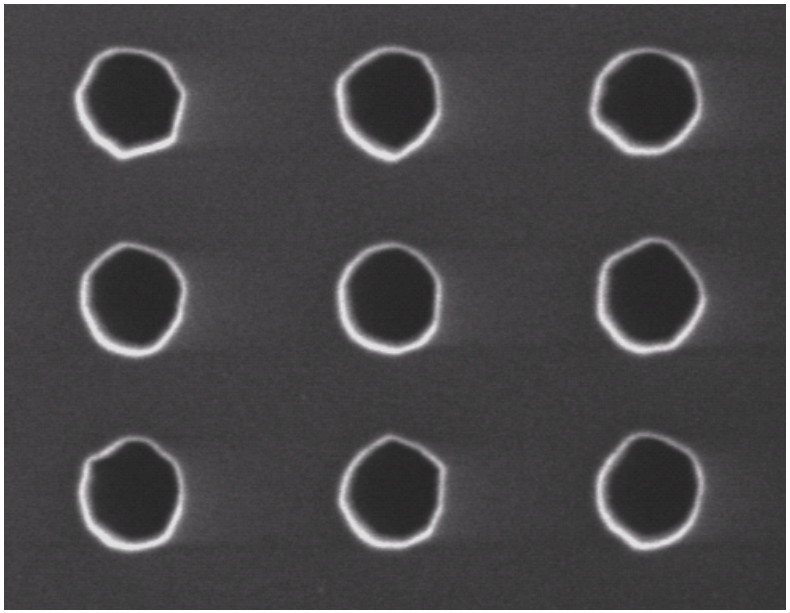
Resist thickness change made:

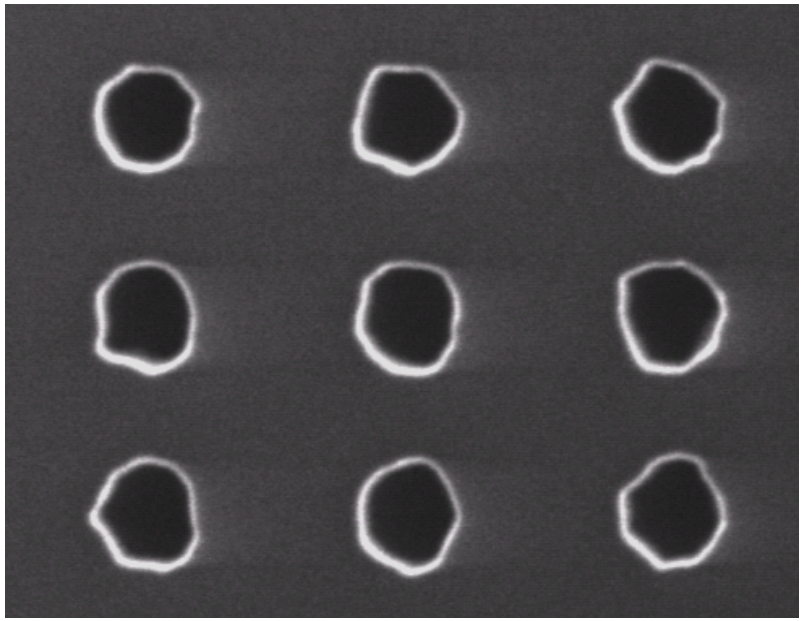
- No **Photo** CD impact
- Slight **Etch** CD impact
- Major impact to **Breakdown Voltage** from contact to unrelated metal



Contact Hole Edge Roughness
Andrew Habermas, Cypress Semiconductor
SPIE Technical Forum, March 2004

Problem Addressed



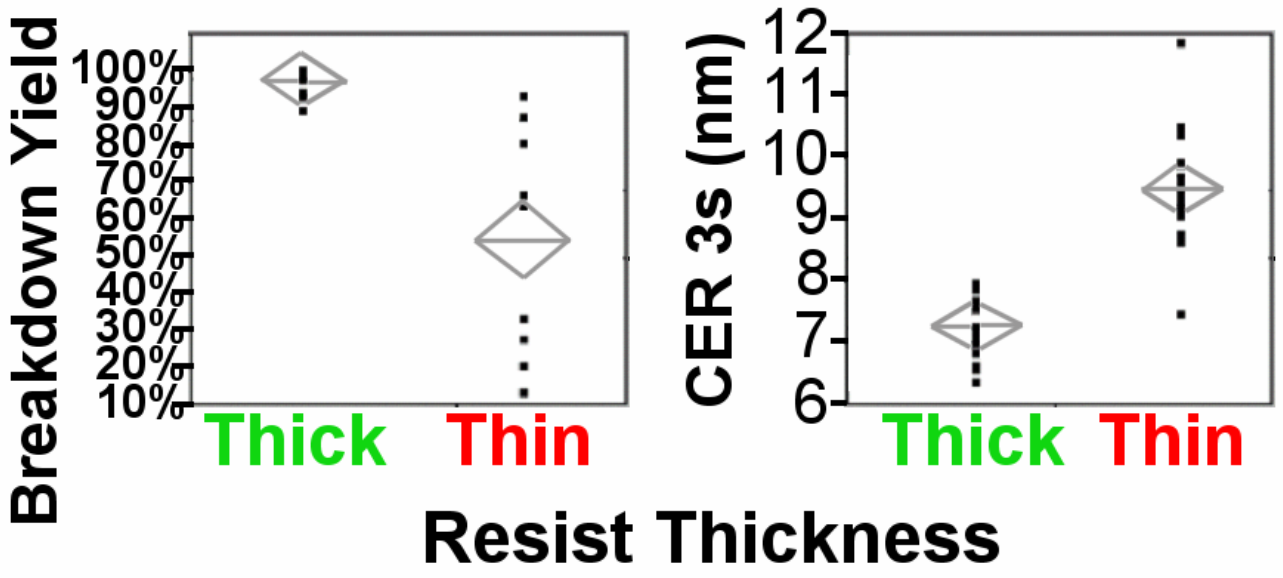


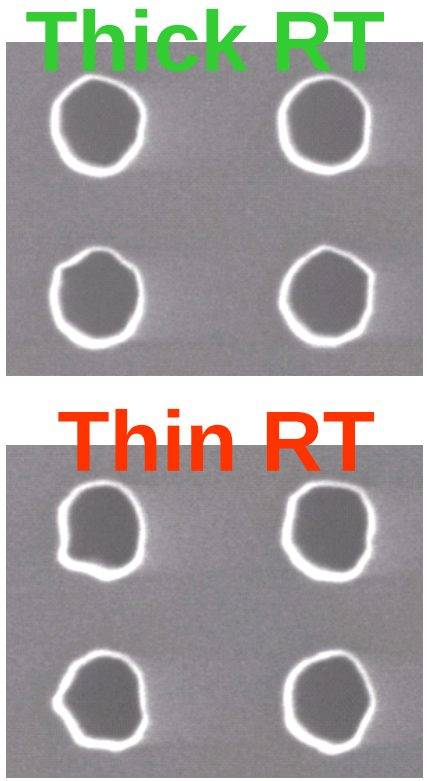
Figures Above: Images of etched contacts using thick resist (left), thin resist (right)

The problem addressed was to develop and evaluate algorithms capable of quantifying the roughness differences for these two contact processes. Other algorithm goals were scalability and integration.

Conclusions

- Contact Edge Roughness (CER) & CL distinguished between four sets of contact samples
- CER can explain the observed electrical breakdown failures in a 0.13µm SRAM process





Summary

- Approach for LER metrology was presented
- and its implementation in CD-SEM discussed
- CD-SEM is capable of measuring LER/LWR and CER with performance meeting ITRS requirements
- Roughness measurement can be utilized in production for quantified process monitoring (SPC)
- Roughness change in production environment need to be studied and control limits established

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