Characterization of LER propagation in resists: underlayer interfaces ultra-thin resist films

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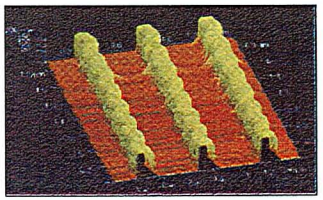
Outline

1. SEM Side-wall Imaging for 3D LER
   a. Absorption and film thickness effects
   b. Post-exposure process effects on resist side-wall
   c. Component studies
   d. Searching for mask contributors
   e. Resist architecture effects
2. LER Effects on Ultra-thin Resists on Underlayers
   - Chemical and physical properties
   - Possible thin-film contributions to LER
   - Patterning Results
3. Summary

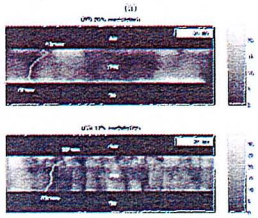
Previous Resist Pattern Side-wall Work

Johann Foucher, CEA/LETI, Proc. of SPIE Vol. 6518, (2007)



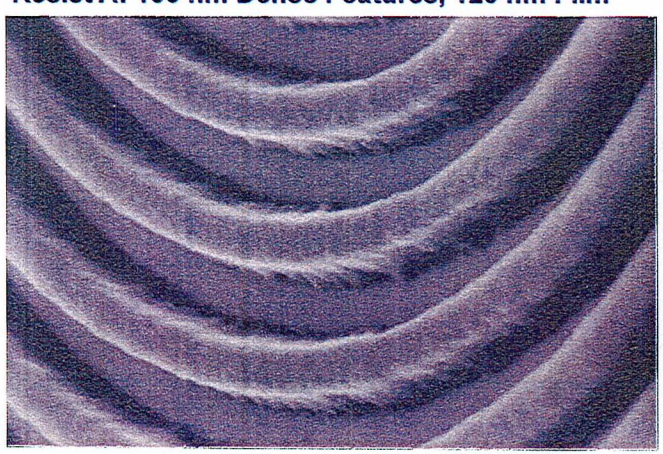
LER both increases and becomes less isotropic as the resist side-wall approaches the substrate interface

Comparison the CD-AFM and CD SEM (3D cross sections)

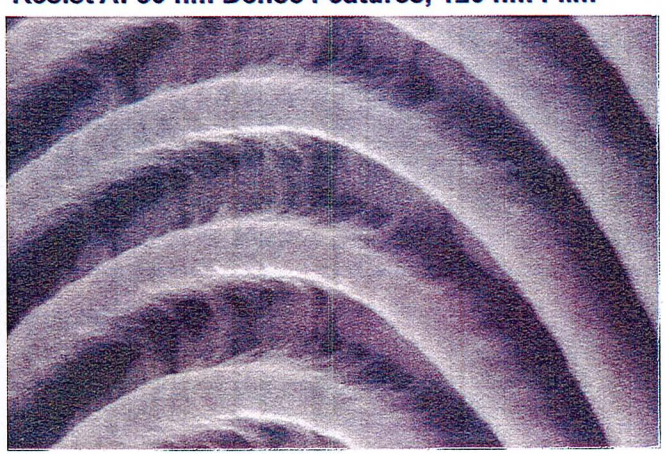


Franco Cerrina, JVSTB 20 (6), 2002
Geoffrey Reynolds, JVSTB 17(2), 1999

Resist A: 100 nm Dense Features, 120 nm Film



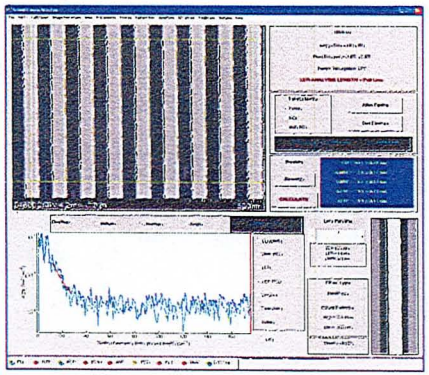
Resist A: 80 nm Dense Features, 120 nm Film



Film Thickness Effects: Resist A , 200nm Film

Horizontal Rippling at the top, but anisotropic

Resist A at 200nm Film Thickness



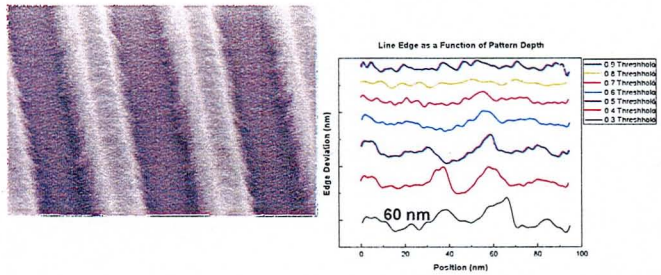
CD = 99.1 nm
LER= 4.9 nm

Top down 1:1

Doesn't tell you the whole story here!

Film Thickness Effects: Resist A, 200nm Film

Edge LER Correlation as a function of depth



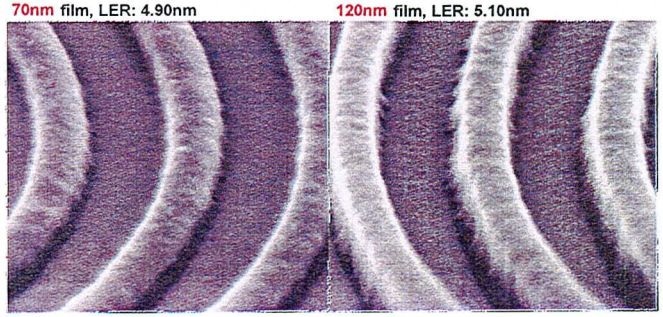
The top most and bottom LER edges do not correlate, but correlated side-wall roughness (CSR) is observed starting at ~140 nm of the pattern sidewall.

Resist Thin Film Effect

100nm dense features

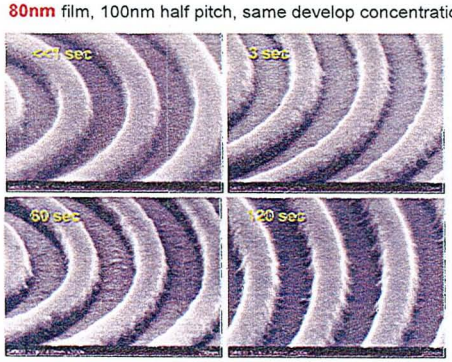
70nm film, LER: 4.90nm

120nm film, LER: 5.10nm



Resist B, Develop Time Tests

80nm film, 100nm half pitch, same develop concentration



Dose matched top down analysis

Significant changes are **not** observed in top down LER analysis

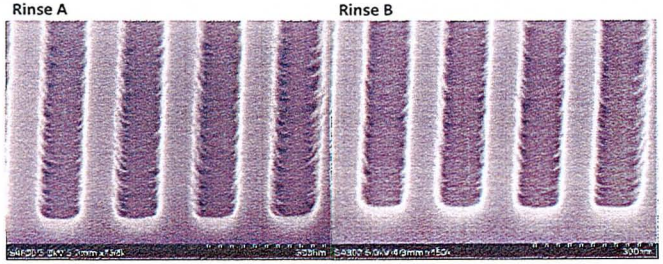
Qualitative side-wall observations show roughening for the longer develop times

Side-wall Changes with Rinse Tests

80nm film thickness

Rinse A

Rinse B



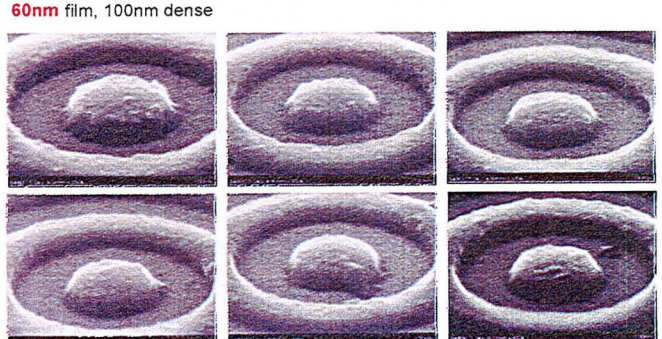
CD = 89.1 nm
Average LER = 5.7 nm

CD = 92.2 nm
Average LER = 4.4 nm

+ 20% reduction in LER

Mask Effects, Shot to Shot Correlation

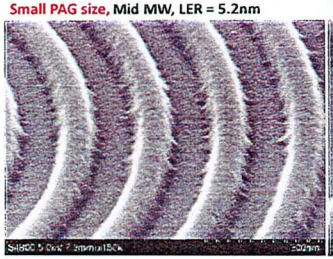
60nm film, 100nm dense



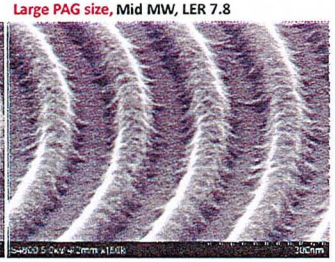
The larger pillars measure ~12nm on average, observed to be random and not related to mask

Resist Component Studies: PAG Size Effects

Small PAG size, Mid MW, LER = 5.2nm



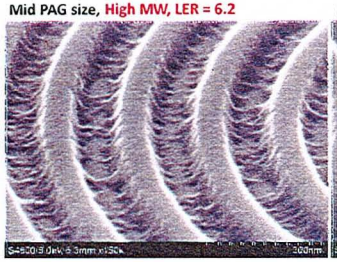
Large PAG size, Mid MW, LER 7.8



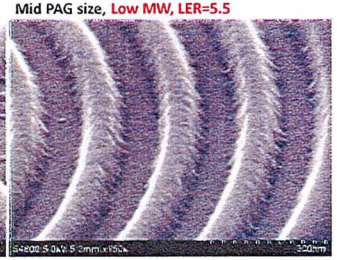
Significant LER increase

Resist Component Studies: Molecular Weight

Mid PAG size, High MW, LER = 6.2



Mid PAG size, Low MW, LER=5.5



Not as drastic as the PAG size effect

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2. **LER Effects on Ultra-thin Resists on Underlayers**
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Chemical and Physical Properties of Underlayers

	GFC/LBNL Tested					
Formulations	Sample A	Sample B	Sample C	Sample D	Sample E	Sample F
Inorganic	Yes	Yes	Yes	Yes	Yes	Yes
M1 loading*	4.5	0	0	0	0	0
M2 loading*	2.5	4	0	1.5	1.5	1.5
M3 loading*	0	0	0	0	3	3
M4 loading*	0	0	100	0	0	0
AP Loading*	6.5 (AP1)	5 (AP1)	0	8 (AP2)	0.5 (AP1)	8 (AP2)
Zisman SE	33.09	32.45	35.43	34.08	34.22	34.45
Geometric Model Dispers	18.81	20.30	6.96	11.70	12.62	10.74
Geometric Model Polar	16.20	13.76	46.08	39.09	36.03	40.76
Contact Angle	69.67	72.10	48.4	48.33	50.73	47.77

Surface energy and contact angle are key parameters for BARC optimization

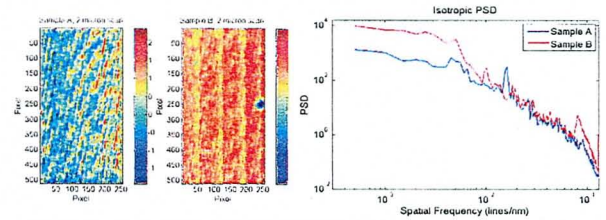
A Closer Look at the Physical Properties

Three samples that were isolated to be the better performers

	Sample A	Sample B	Sample C
Zisman Method, Surface Energy	33.09	32.45	35.43
Geometric Model, Dispersion	18.81	20.30	6.96
Geometric Model, Polarity	16.20	13.76	46.08
Dispersion/Polarity Ratio	1.16	1.47	0.15
Contact Angle	69.67	72.10	48.40

Sample C is very different in terms of contact angle and surface energy

2D Topography Analysis of the Underlayers Films

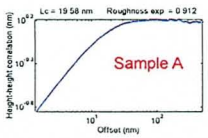


Underlayer	Total Power (nm^2)	RMS Rough (nm)	Roughness Correlation length (nm)
Sample A	0.344	0.53	54.68
Sample B	1.04	0.85	82.00

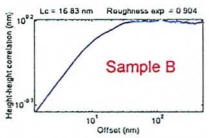
Sample B has larger dispersion/polarity and contact angle

Patterned LER Exponent and Correlation

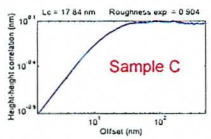
0 nm Defocus, Center Dose, CD = 39 nm



0 nm Defocus, Center Dose, CD = 38.8 nm



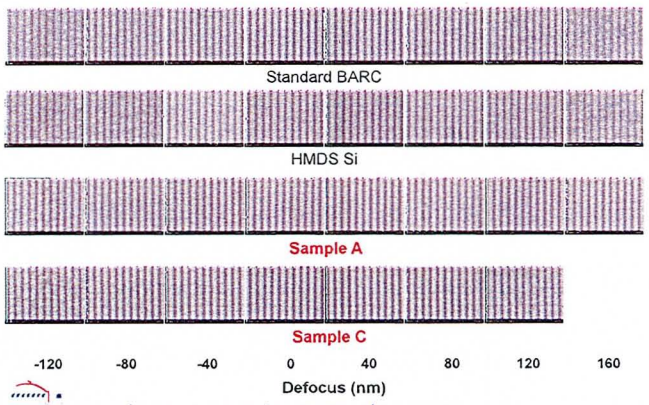
0 nm Defocus, Dose Center, CD = 39.7 nm



Underlayer	CD(nm)	Roughness Correlation length	Roughness Exponent
HMDS Si	40.7	15.90	0.90
Std. BARC	38.6	16.80	0.91
Sample A	39.0	19.58	0.91
Sample B	38.8	16.83	0.90
Sample C	39.7	17.84	0.90

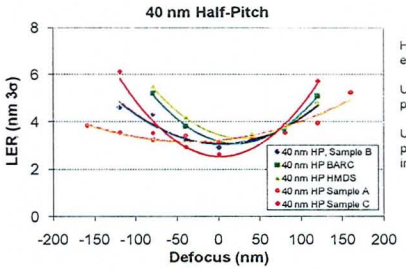
Underlayer film roughness properties does not factor for LER

40 nm L/S vs Focus



LER Response through substrates

70 nm Film Thickness, standard process conditions

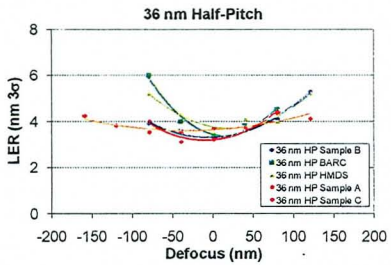


HMDS, Standard BARC, Underlayer B are equivalent to within process error

Underlayer A: superior through-focus performance, lack 3σ LER improvement

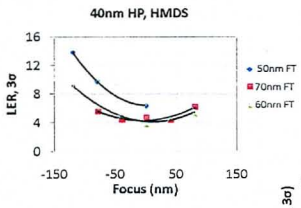
Underlayer C: superior 3σ LER performance, lack through-focus improvement

Behavior Extends to smaller pattern widths

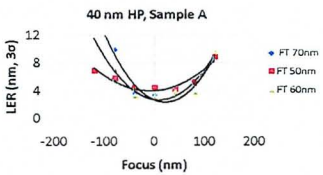


36 nm half pitch trends are similar to 40 nm half pitch data

LER Response Through Resist film Thickness



Increases in LER in thinner films



Detailed studies to be completed

Summary

- 3D SEM imaging shows the side-wall roughness to be correlated
- CSR behavior in thin-films are invariant across resist platforms
- Underlayer stack roughness properties do not correlate to patterned resist LER
- Chemical properties do correlate in a way that is not clearly understood at this point
- Strong influence from underlayers on process performance is observed
- Future Work: Quantitative 3D-SEM side-wall analysis of resists on underlayers stacks

Special Thanks…

- Tom Wallow
- Honeywell team
- CXRO
- The MET Team
- Chris Anderson for resist samples