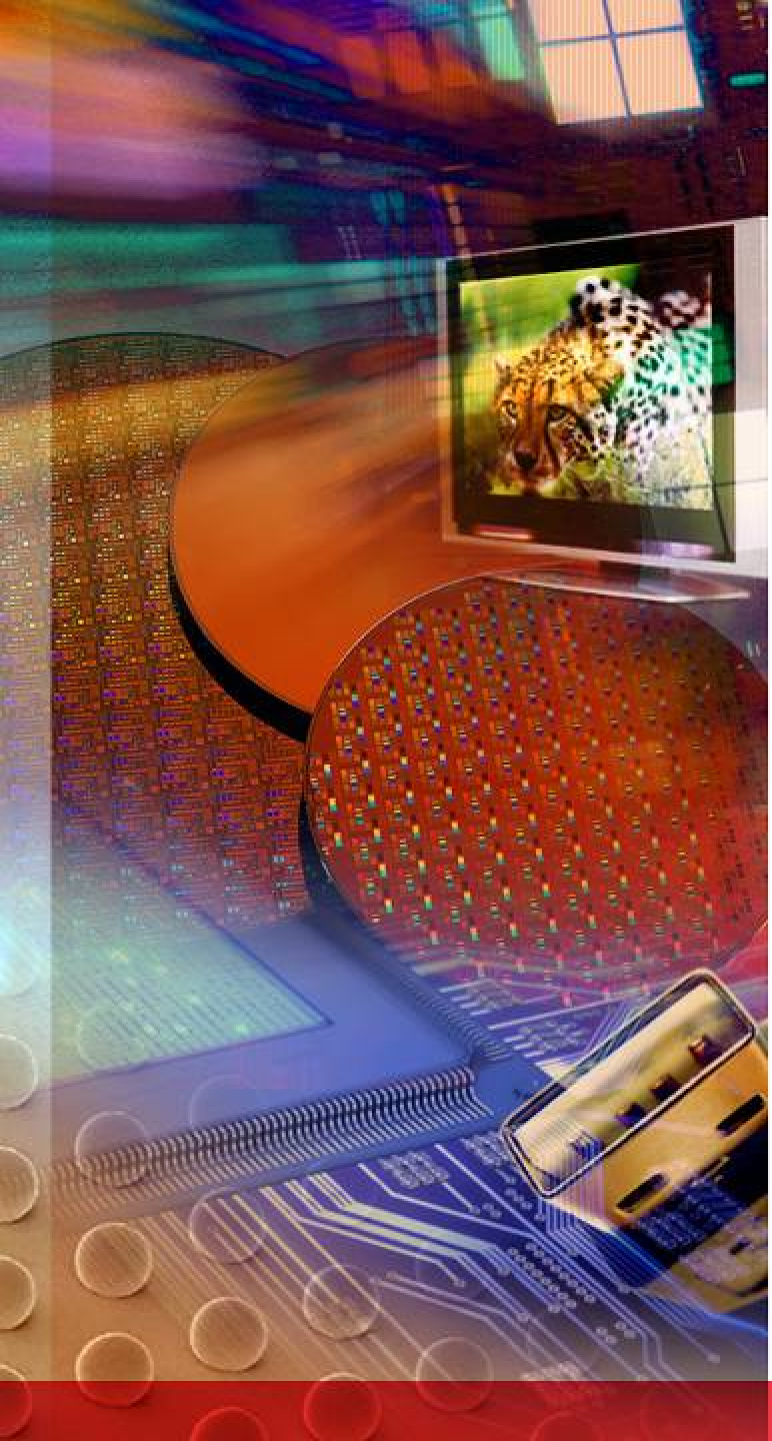


Electronic Materials

EUV resist challenges of image collapse, LWR, sensitivity, and resolution

James W. Thackeray
October 17, 2010

Presentation Outline

- Resist Material Challenges for EUV Technology
- Dow Material Approach
- RLS Advancement
- Pattern Collapse Advancement
- Future Challenges

Critical Challenges for EUV Resists

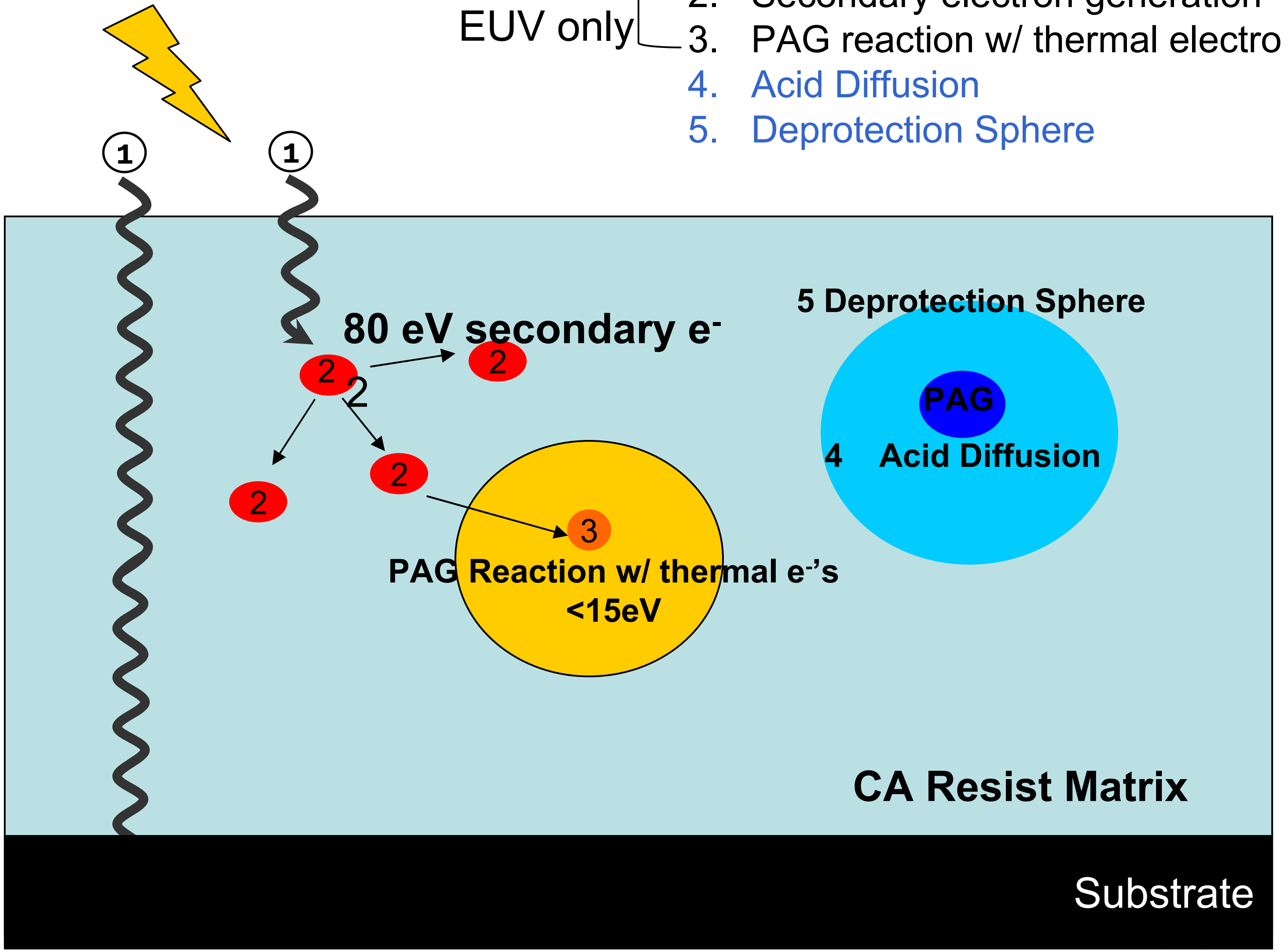
Challenge	Areas to work on
Fundamental EUV interaction with Resist Material	Electron blur, line slimming, negative resist behavior, acid yield
Resolution	Polymer-bound PAG, low activation LG, swelling reduction
LWR	Polymer-bound PAG, etch trim, rinse, polymer homogeneity
Photospeed	EUV sensitization, higher PAG loading
Etch Resistance	Lower Ohnishi parameter approach
Pattern Collapse	Lower A/R, UL matched for adhesion, surfactant rinse
Outgassing	PAG byproducts from ionization, LG and solvent effects, other species?
Defects	HSP solvents, aggregation elimination
Quality Control	EUV photospeed test, EUV chemical signature requirement

EUV Reaction Mechanism

13.4nm [92eV] source

1. Photon Absorption by Resist Matrix
2. Secondary electron generation
3. PAG reaction w/ thermal electrons
4. Acid Diffusion
5. Deprotection Sphere

EUV only (2., 3.)



EUV Sensitization Mechanism: Higher Acid Yield Through sensitization

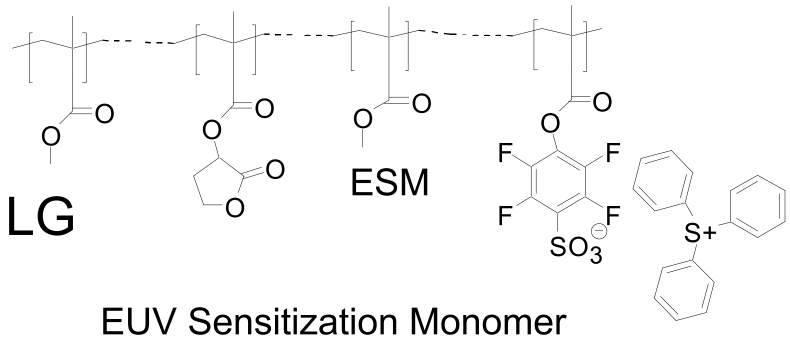
- EUV photons ionize polymer to create 3-4 secondary electrons
- Secondary electron yield can be increased through increased EUV absorption [ie F-containing monomer] or low ionization potential monomer [ie naphthyl monomer]
- Acid Yield increase improves latent acid image in resist

1) $PH + h\nu\ (13.4nm) \longrightarrow [PH]^{\bullet +} + e^{-}$

2) $[PH]^{\bullet +} \longrightarrow [P]^{\bullet} + H^{+}$

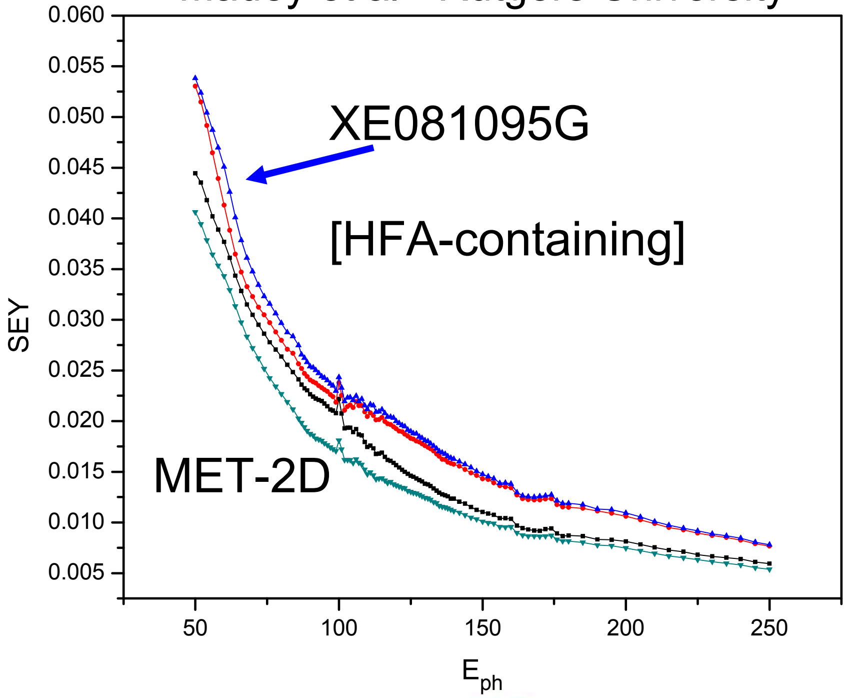
3) $AG + e^{-} \longrightarrow G^{-} + A^{\bullet}$

4) $G^{-} + H^{+} \longrightarrow HG$

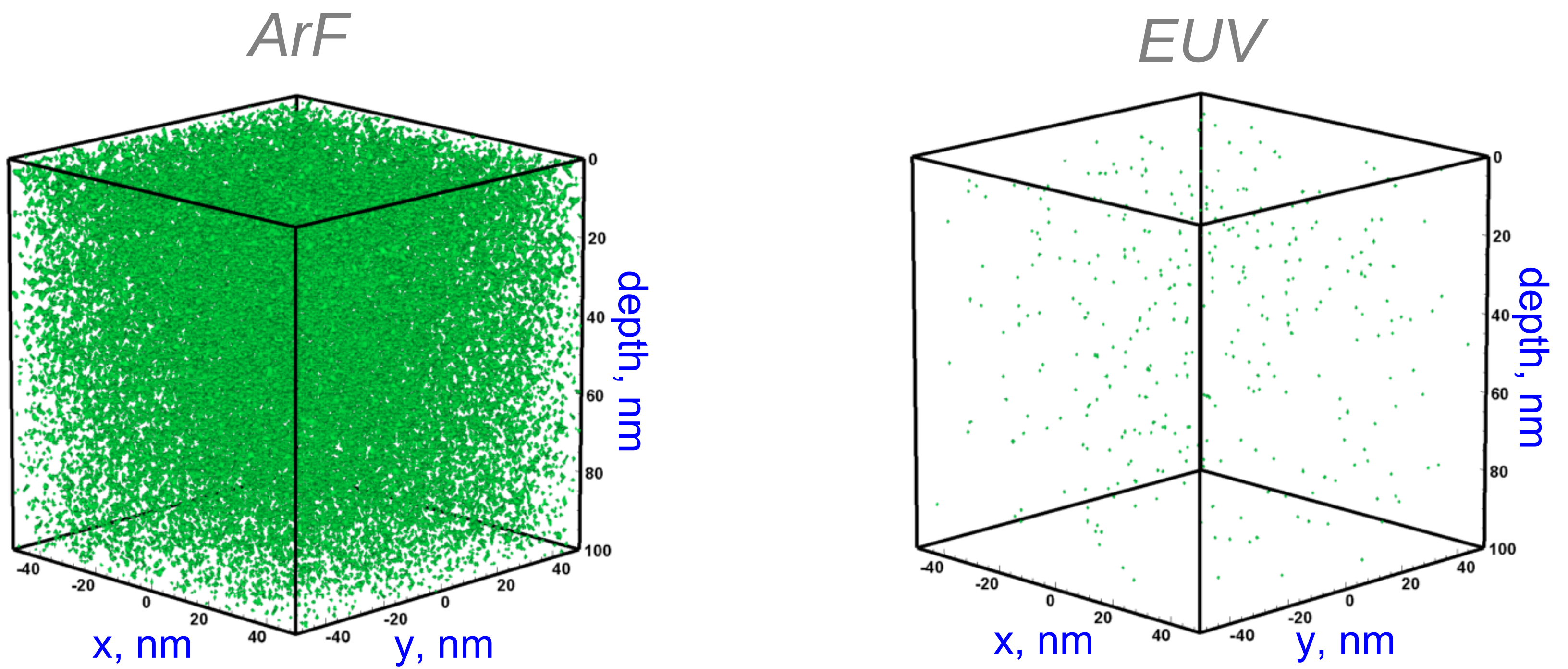


EUV Sensitization Monomer

Madey et al - Rutgers University



Photon absorption by a volume in ArF and EUV at 10 mJ/cm^2



$$ArF, 10\,mJ/cm^2, \alpha = 4/um$$

$$n_{absorbed} = 366528,\ E_{absorbed} = 2354\,keV$$

$$EUV, 10\,mJ/cm^2, \alpha = 4/um$$

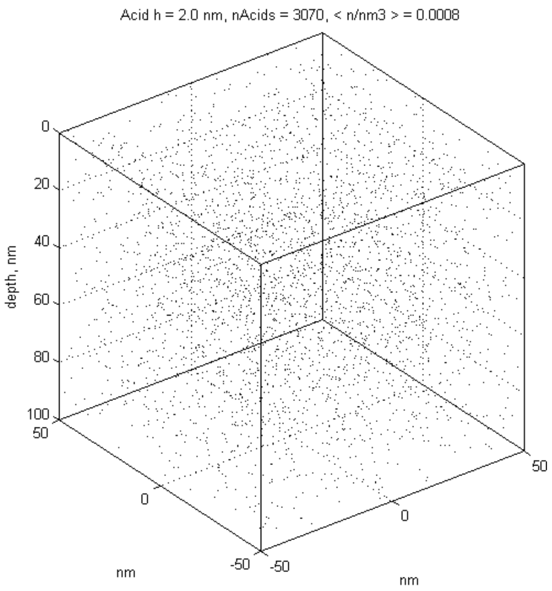
$$n_{absorbed} = 25328,\ E_{absorbed} = 2326\,keV$$

- About 14x more photons absorbed at *ArF* than *EUV*
- Average absorbed energy is the same, about 2.3 eV / nm^3

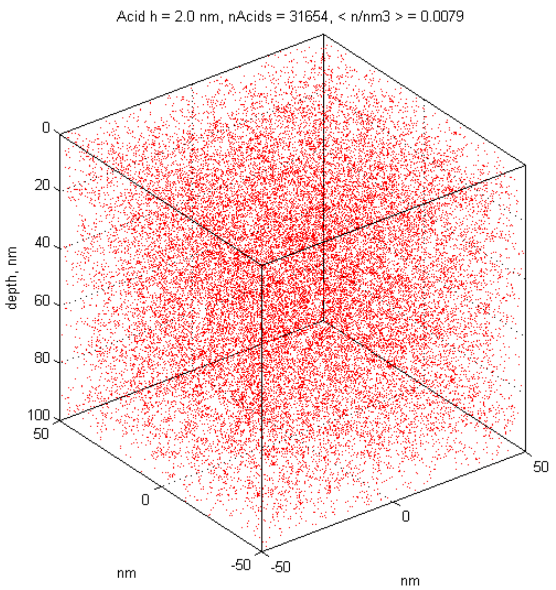
Biafore, Thackeray et al SPIE 2009

Simulated acid yield: direct photolysis vs. ionization w/scattering

13.5 *nm*, dose = 10 mJ/cm^2, *B* = 4.5 / um, open frame, 0.25 NA, 0.5 sigma



$$Yield = \Phi = 0.122$$



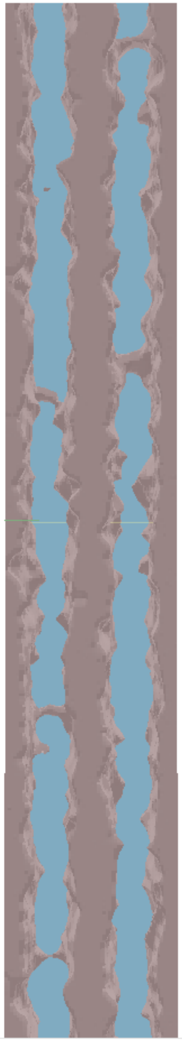
$$Yield = \Phi = 1.27$$

- An exposure mechanism which considers ionization and electron scattering may explain acid yields and sizing doses observed at EUV

Courtesy John Biafore KLA- Tencor INC

Simulated Effect of Exposure Dose on Resist LWR

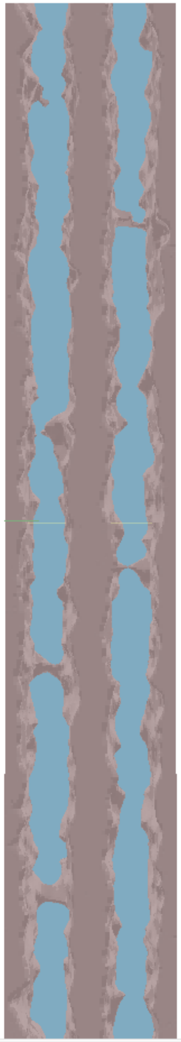
13.5 nm, 0.25 NA, 0.5 sigma, 30 nm lines and spaces, PROLITH X3.1.1 stochastic simulator



$E_{SIZE} = 7.25\ mJ$

$\overline{CD} = 30.2\,nm$

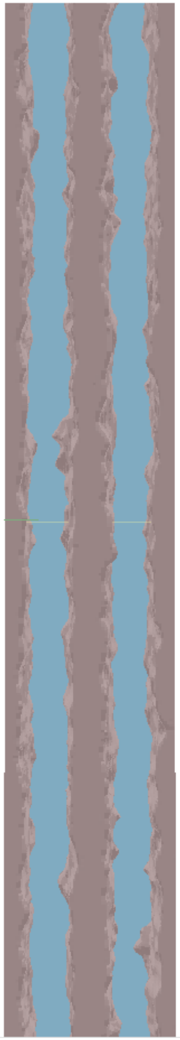
$LWR = 7.4\,nm$



$E_{SIZE} = 15\ mJ$

$\overline{CD} = 30.1\,nm$

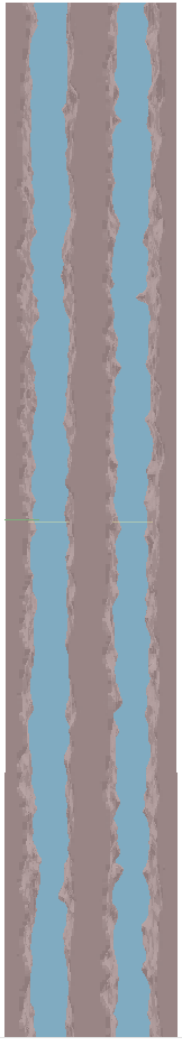
$LWR = 5.4\,nm$



$E_{SIZE} = 30\ mJ$

$\overline{CD} = 29.6\,nm$

$LWR = 4.5\,nm$



$E_{SIZE} = 60\ mJ$

$\overline{CD} = 30.4\,nm$

$LWR = 3.8\,nm$

Lowering exposure dose clearly degrades LWR

- Simulation using EUV calibrated stochastic resist model
- Photospeed is adjusted by quencher addition

Courtesy John Biafore, KLA- Tencor

Genealogy of Methacrylate platforms

MA

XP-6627G

25nm 1:1 @ Es~49mj/cm^2
F4-PAG

XP-6627A

30nm 1:1 @ Es~7.8mj/cm^2
EUV sensitizer

XE-081095G

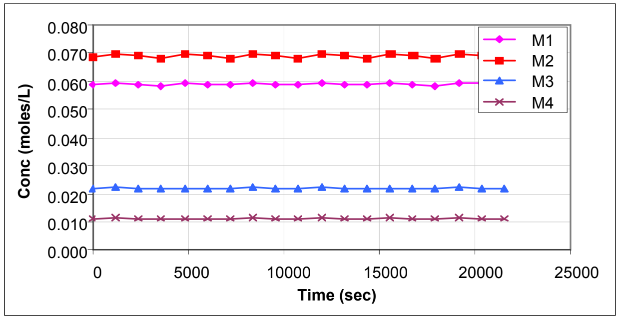
ESM3 (Oct/09) LWR ~5
@ 30nm/Es~13 mj/cm^2

Kinetic study

XE-081095AJ

Process DOE

Homogeneity: LWR
Polymer: under analysis



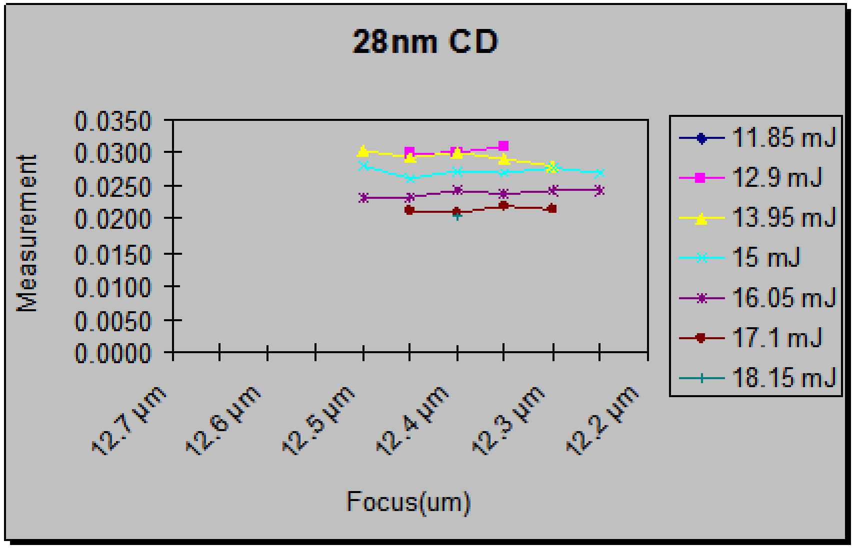
Low Ea/LWR: 4.3 @28nm
PS: 15 mj/cm^2

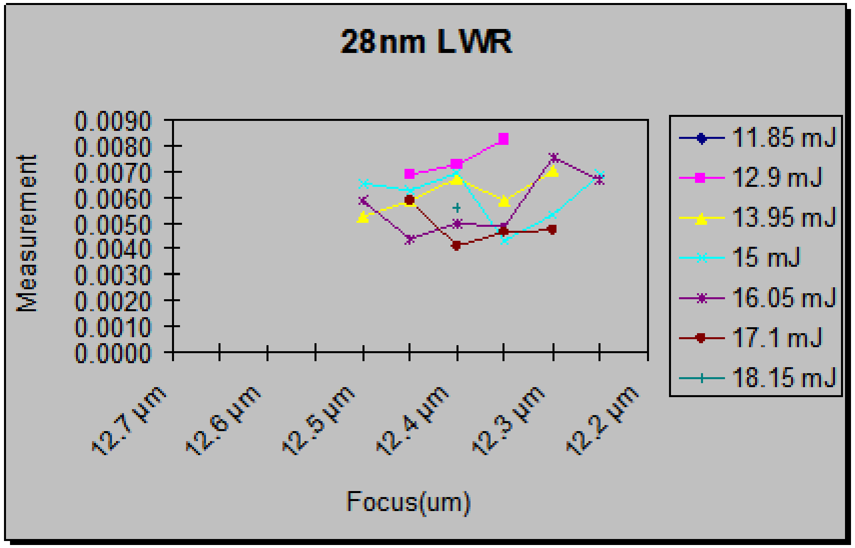
JMP DOE
PAB/PEB etc

XE-100291AH

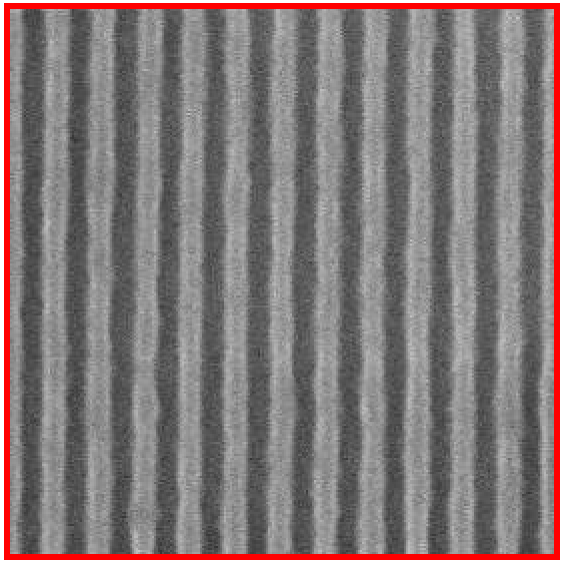
New PAG
LWR: 4.4
PS: 16 mj/cm^2

Process DOE: XE-081095AJ on Albany eMET





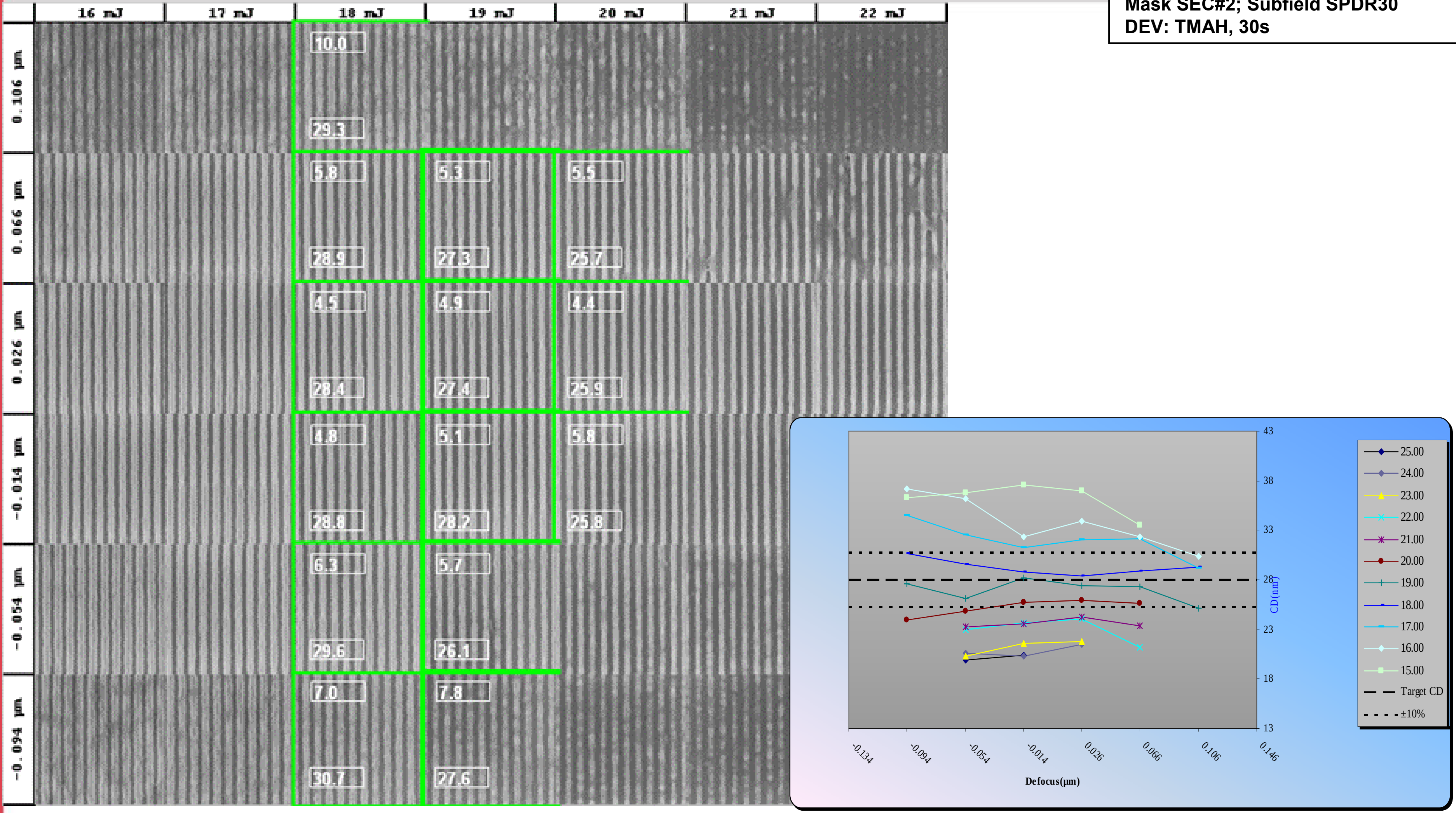
--+ best process from DOE:
54nm thickness, 100CPAB, 95CPEB



PS: 15 mj/cm2
LWR:4.3nm

Albany ADT: XE-081095AJ 30nm HP

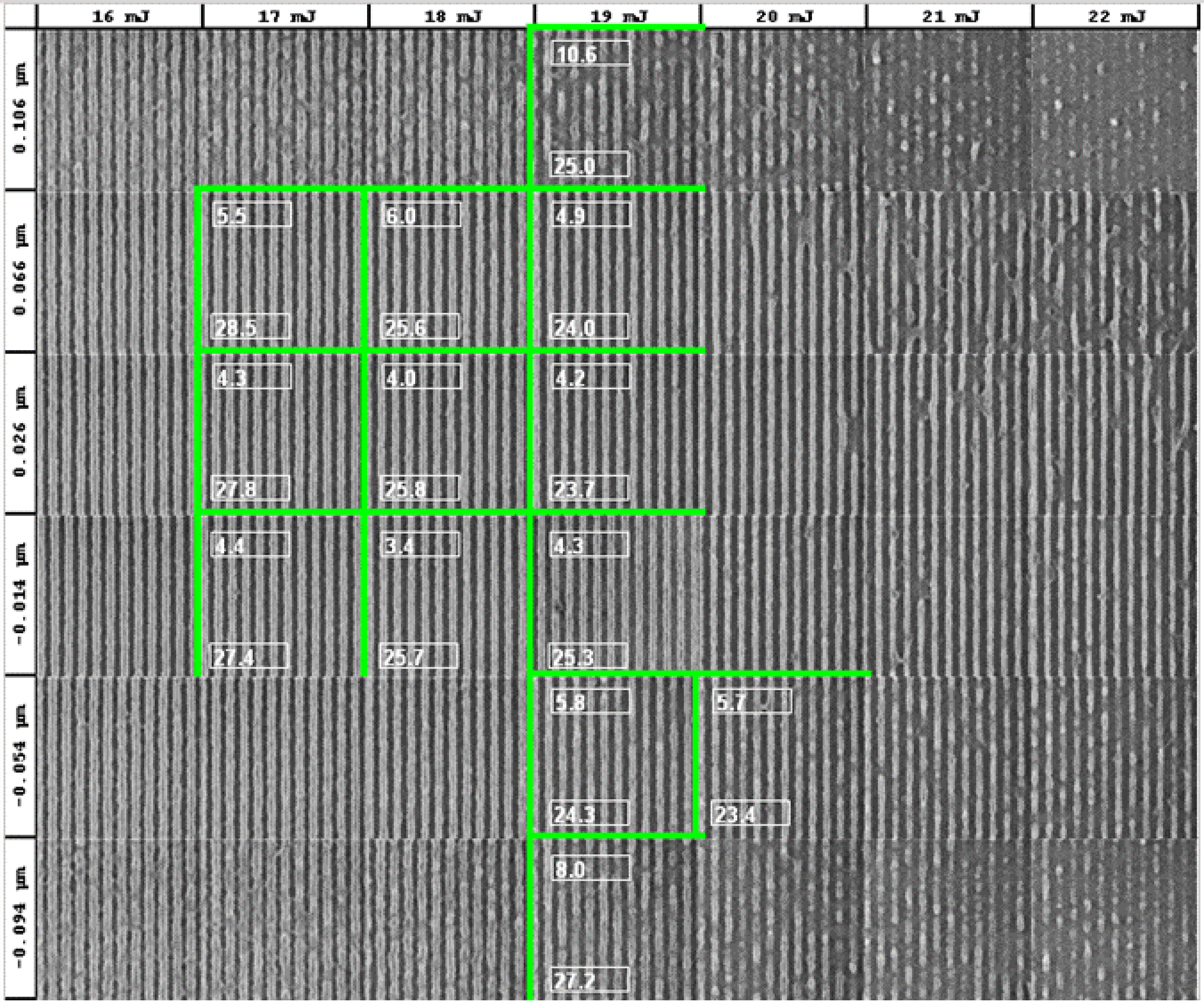
Resist: 60nm XE081095AJ
PAB=140°C/90s; PEB=100°C/60s
UL: XU081104AA@250Å; 205°C/60s
EXP:ADT Albany, NA=0.25; 0.50σ
Mask SEC#2; Subfield SPDR30
DEV: TMAH, 30s



- Target 2nm offset to 30nm feature due to typical offset from 9380 to Cross Section

Albany ADT: XE-081095AJ 28nm HP

Resist: 60nm XE081095AJ
PAB=140°C/90s; PEB=100°C/60s
UL: XU081104AA@250Å; 205°C/60s
EXP:ADT Albany, NA=0.25; 0.50σ
Mask SEC#2; Subfield SPDR30
DEV: TMAH, 30s

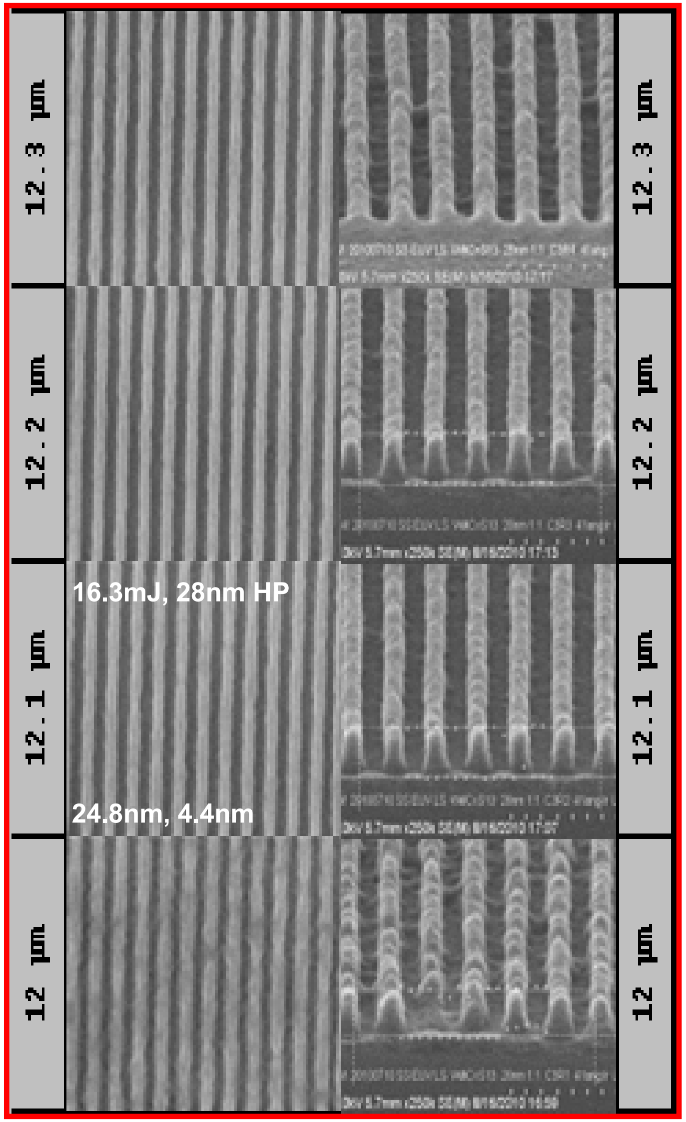


- Target 2nm offset to 28nm feature due to typical offset from 9380 to Cross Section

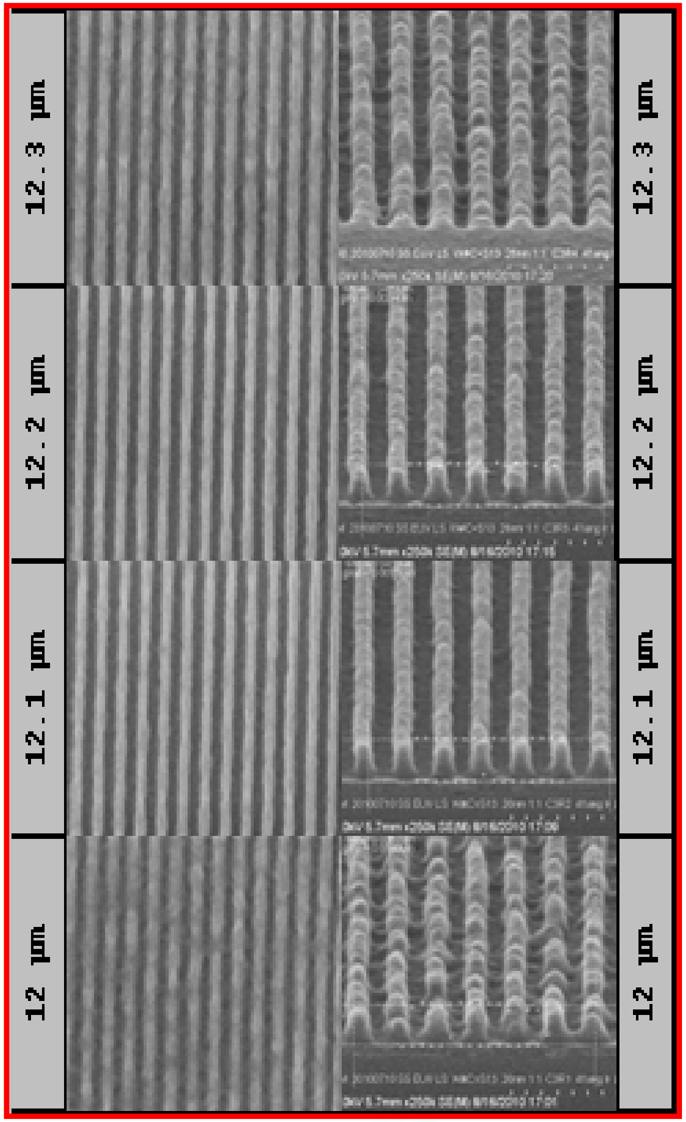
MA

XE-100291AH on Albany eMET

28nm 1:1



26nm 1:1



E=16.3mj/cm2, UL=XU-081104, PAB/PEB=120/90

Electronic Materials

Pattern Collapse

Main reasons for pattern collapse

- **Young's modulus.** The mechanical stiffness of the lines is dominated by the Young's Modulus.
  - **Mechanical stability of resist lines decreases**
    - **Intrinsic decrease of the modulus towards ultra thin films based on the intrinsic decrease of T_g towards thinner films**
- **Unbalanced capillary forces:**

$$\Delta Pi = 2\gamma \bullet \cos\theta \bullet \left(\frac{1}{s_1} - \frac{1}{s_2} \right) HA$$

- γ surface tension of the rinsing liquid

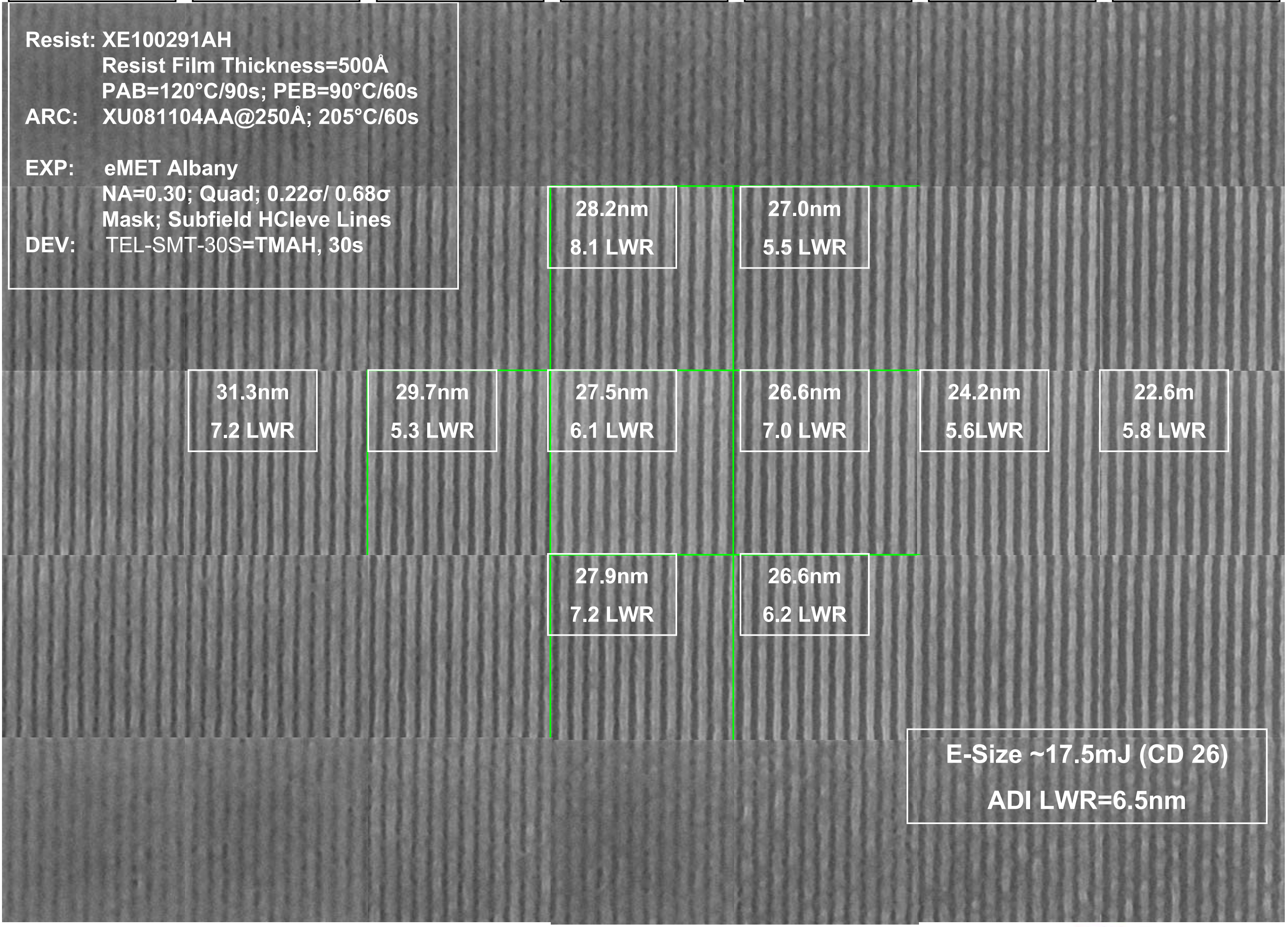
s_1 and s_2 different spaces beside the resist line

H and A – the resist film thickness and the line edge area

θ the contact angle of the rinsing liquid

- **Adhesion between substrate and resist**

eMET 28nm 1:1 Images



Resist: XE100291AH
Resist Film Thickness=500Å
PAB=120°C/90s; PEB=90°C/60s
ARC: XU081104AA@250Å; 205°C/60s

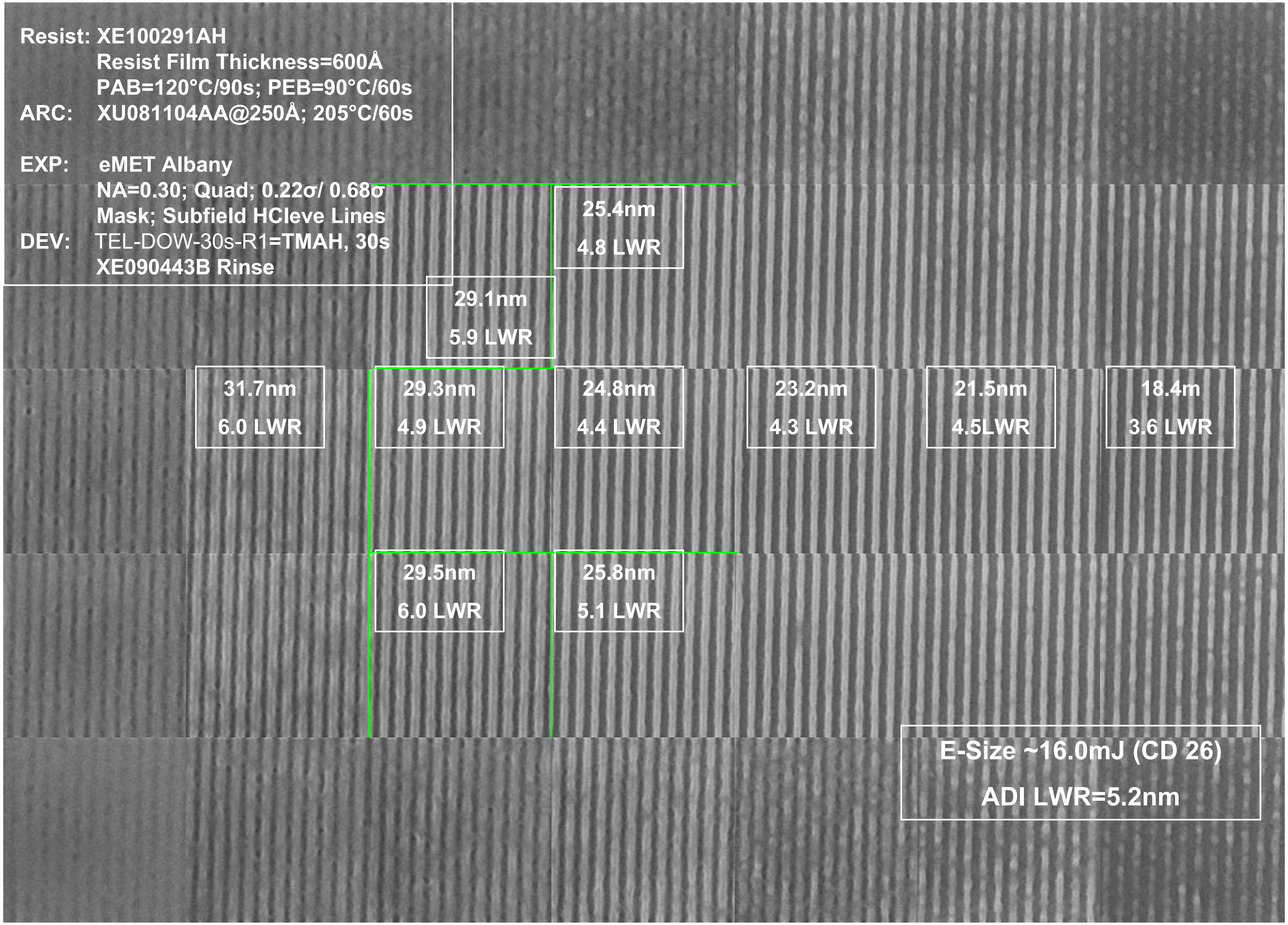
EXP: eMET Albany
NA=0.30; Quad; 0.22σ/ 0.68σ
Mask; Subfield HCleve Lines
DEV: TEL-SMT-30S=TMAH, 30s

	14.01mJ	14.84mJ	15.67mJ	16.50mJ	17.33mJ	18.16mJ	18.99mJ
+200nm							
+100nm				28.2nm 8.1 LWR	27.0nm 5.5 LWR		
0nm		31.3nm 7.2 LWR	29.7nm 5.3 LWR	27.5nm 6.1 LWR	26.6nm 7.0 LWR	24.2nm 5.6LWR	22.6m 5.8 LWR
-100nm				27.9nm 7.2 LWR	26.6nm 6.2 LWR		
-200nm							

E-Size ~17.5mJ (CD 26)

ADI LWR=6.5nm

eMET 28nm 1:1 Images



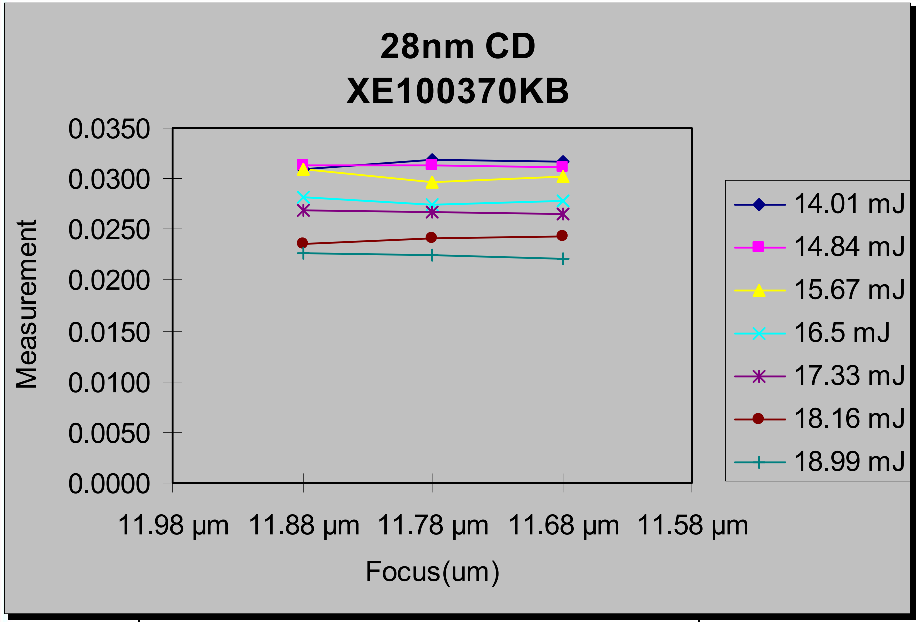
Resist: XE100291AH
Resist Film Thickness=600Å
PAB=120°C/90s; PEB=90°C/60s
ARC: XU081104AA@250Å; 205°C/60s

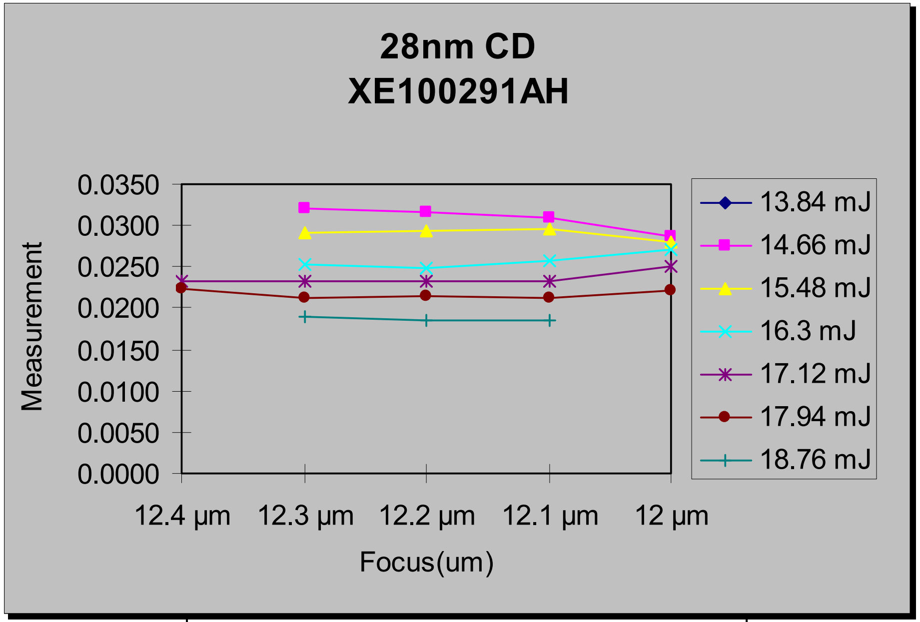
EXP: eMET Albany
NA=0.30; Quad; 0.22σ/ 0.68σ
Mask; Subfield HCleve Lines
DEV: TEL-DOW-30s-R1=TMAH, 30s
XE090443B Rinse

	13.84mJ	14.66mJ	15.48mJ	16.3mJ	17.12mJ	17.94mJ	18.76mJ
+200nm							
+10nm			29.1nm 5.9 LWR	25.4nm 4.8 LWR			
0nm		31.7nm 6.0 LWR	29.3nm 4.9 LWR	24.8nm 4.4 LWR	23.2nm 4.3 LWR	21.5nm 4.5LWR	18.4m 3.6 LWR
100nm			29.5nm 6.0 LWR	25.8nm 5.1 LWR			
-200nm							

E-Size ~16.0mJ (CD 26)
ADI LWR=5.2nm

CD Process Window





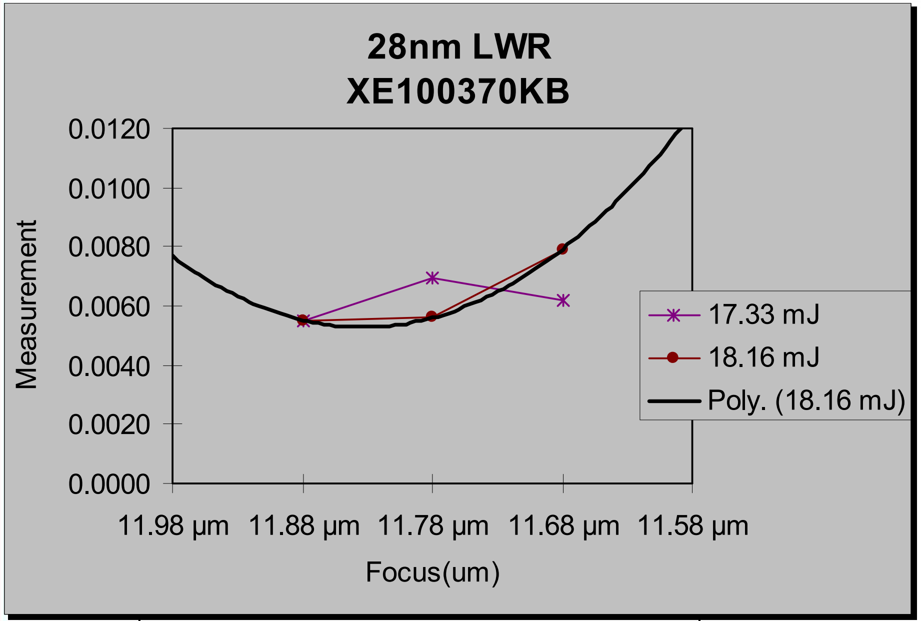
Resist: XE100291AH
Resist Film Thickness=500Å
PAB=120°C/90s; PEB=90°C/60s
ARC: XU081104AA@250Å; 205°C/60s

EXP: eMET Albany
NA=0.30; Quad; 0.22σ/ 0.68σ
Mask; Subfield HCleve Lines
DEV: TEL-SMT-30S**=TMAH, 30s**

Resist: XE100291AH
Resist Film Thickness=600Å
PAB=120°C/90s; PEB=90°C/60s
ARC: XU081104AA@250Å; 205°C/60s

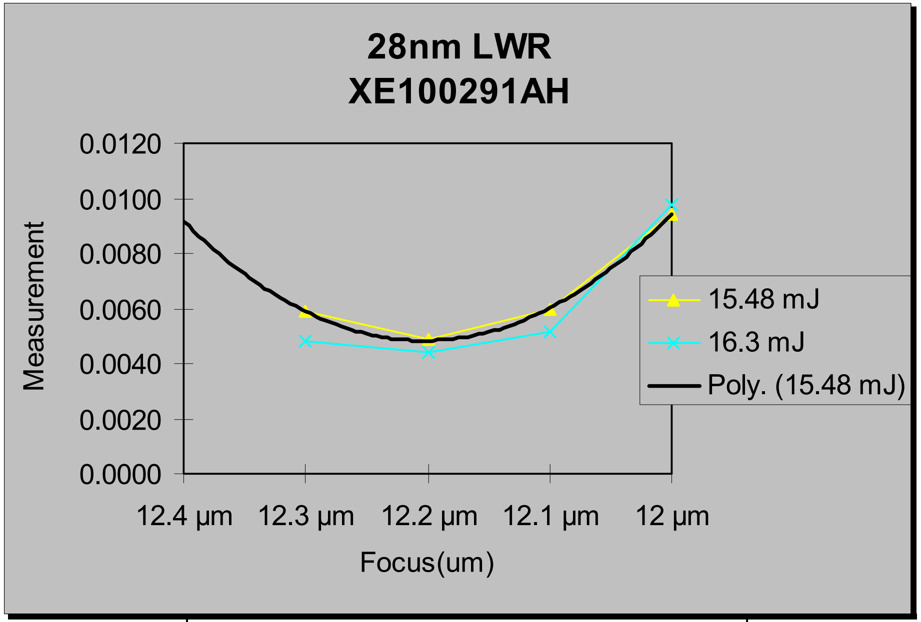
EXP: eMET Albany
NA=0.30; Quad; 0.22σ/ 0.68σ
Mask; Subfield HCleve Lines
DEV: TEL-DOW-30s-R1**=TMAH, 30s**
XE090443B Rinse

LWR Process Window



Resist: **XE100291AH**
Resist Film Thickness=500Å
PAB=120°C/90s; PEB=90°C/60s
ARC: **XU081104AA@250Å; 205°C/60s**

EXP: **eMET Albany**
NA=0.30; Quad; 0.22σ/ 0.68σ
Mask; Subfield HCleve Lines
DEV: TEL-SMT-30S**=TMAH, 30s**

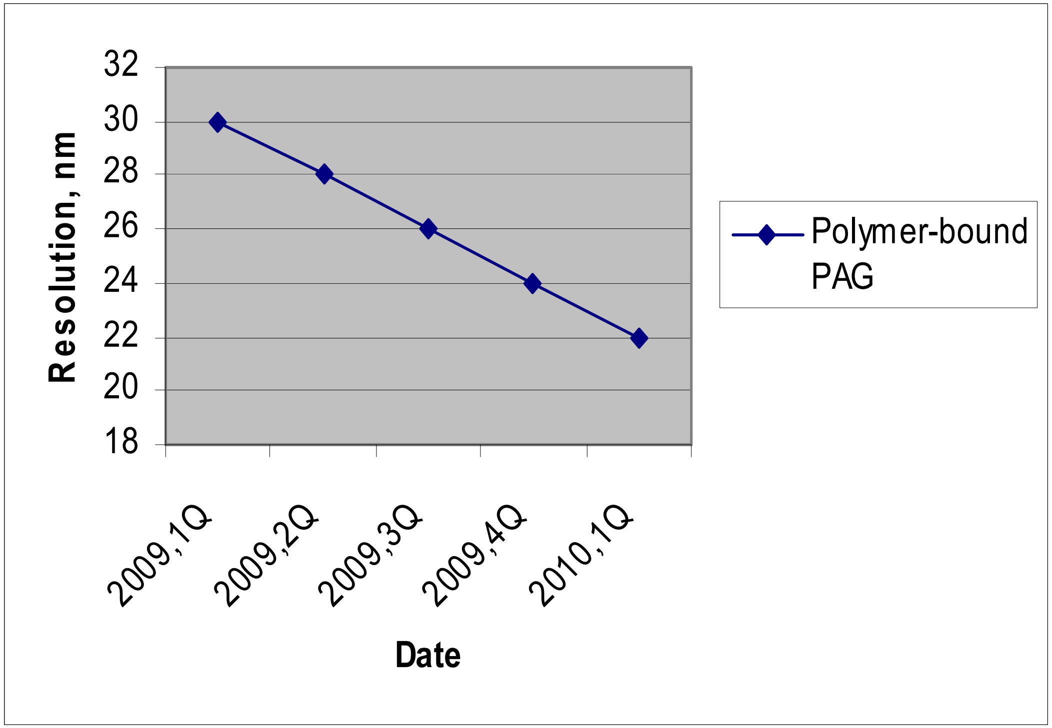


Resist: **XE100291AH**
Resist Film Thickness=600Å
PAB=120°C/90s; PEB=90°C/60s
ARC: **XU081104AA@250Å; 205°C/60s**

EXP: **eMET Albany**
NA=0.30; Quad; 0.22σ/ 0.68σ
Mask; Subfield HCleve Lines
DEV: TEL-DOW-30s-R1**=TMAH, 30s**
XE090443B Rinse

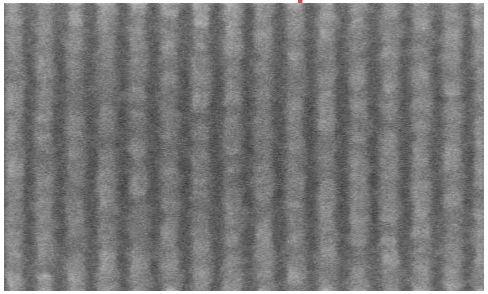
SEMATECH eMET : Improved Resolution Polymer Bound PAG

- Continuous improvement in resolution
  - Low Activation Resists with Reduced swelling

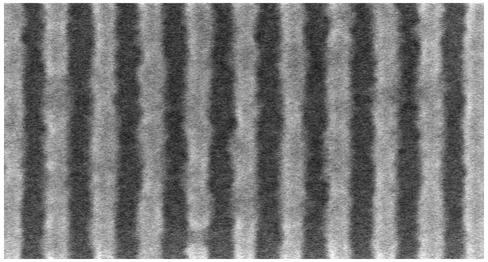


Quadrapole

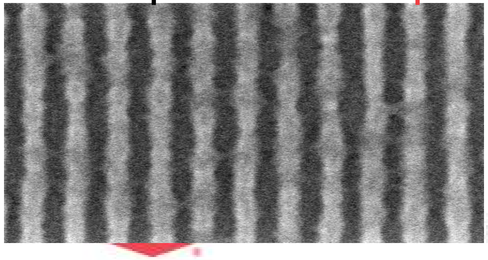
22nm hp



C-Dipole 22nm hp



C Dipole 20nm hp



Summary

- There are many important parameters to optimize for EUV Resist
- RLS improvement:
    - Polymer-bound PAG
    - High EUV quantum yield and High EUV absorption
    - Developer contrast also important
- Pattern Collapse improvement:
    - Surfactanated Rinses help methacrylate LWR
    - Aspect ratios should more realistically be 2:1
- EUV access is a critical path to better resists!

Dow® Electronic Materials