Optimization of Low Diffusion EUV Resist on Different Substrates

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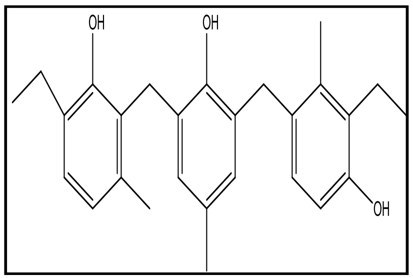
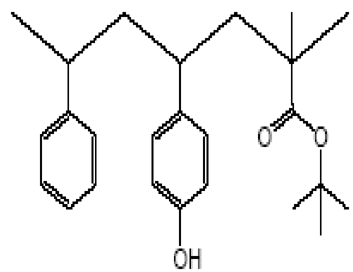
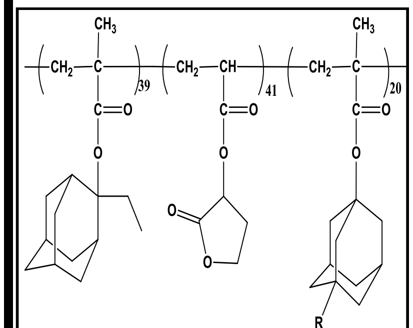
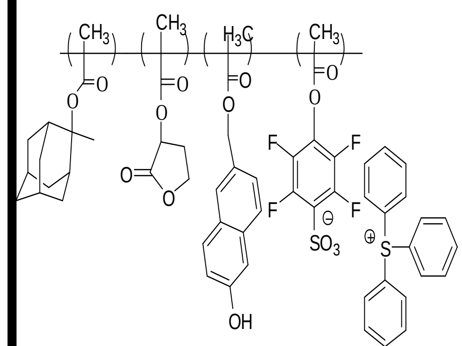
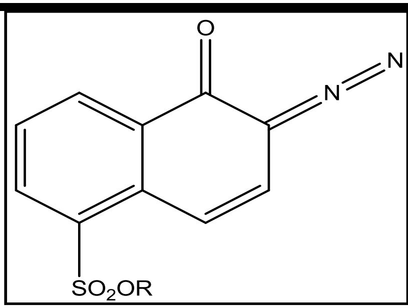
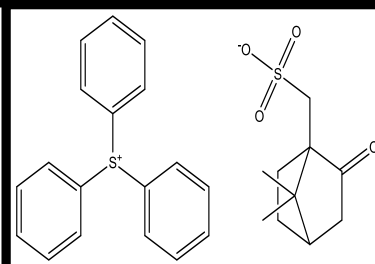
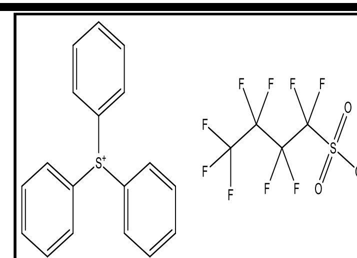
Talk Outline

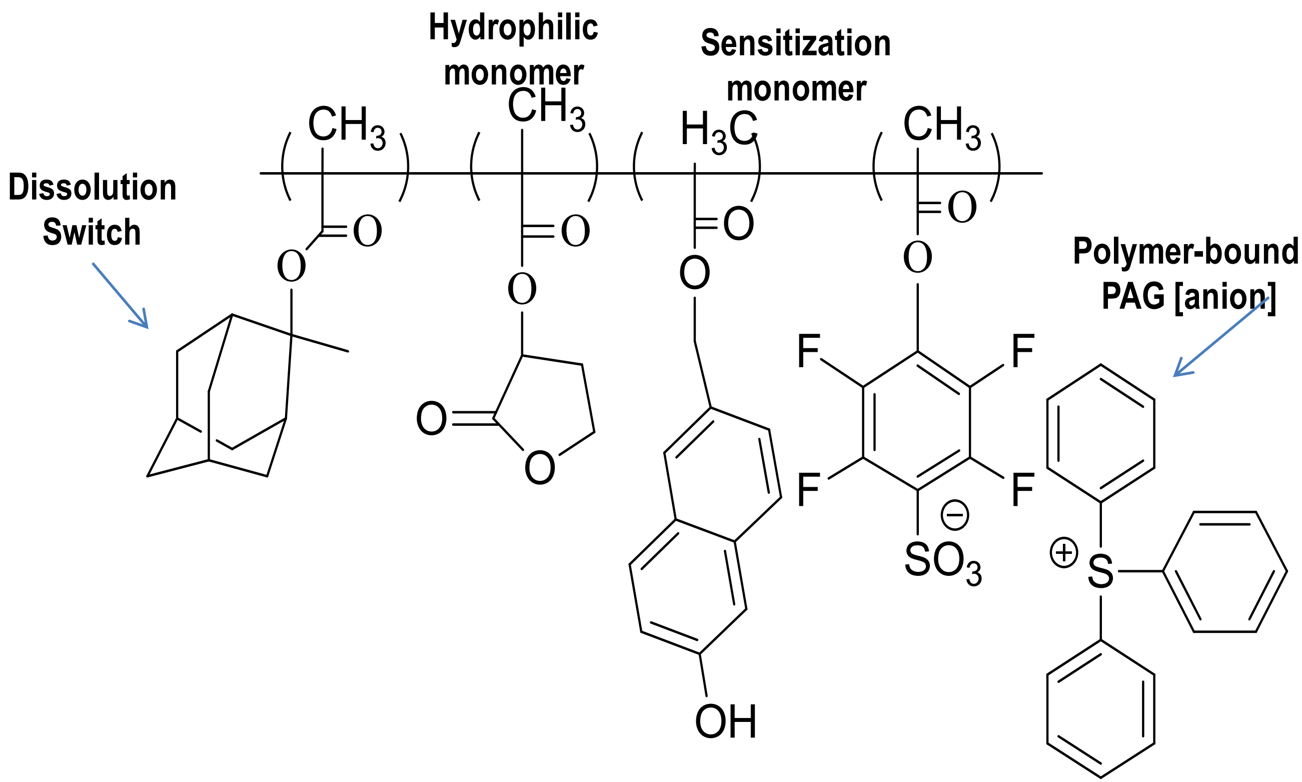
- Scaling Through Wavelength Reduction
  - We must make wavelength reduction work, DSA augments lithographic imaging
  - CA resist design allows weak source to be utilized
  - Polymer and PAG design have met the challenge in previous generations
  - Polymer-bound PAG offers lower blur CA resist
- Low Diffusion Resist Design that has resolution, sensitivity and LWR
  - Anion- bound PAG lithographic polymers enable 20-nm lithography, can we extend to sub-20nm?
  - Improve resist quantum yield, resist absorption and density, reduce acid blur
- LWR improvement through improved acid quantum yield, resist absorbance
  - Models show resist with high acid quantum yield and higher resist absorbance improves LWR
- Substrate optimization for LWR and PCM
  - Pattern Colllapse Margin improved with substrate optimization for CTE and surface energetics

Imaging at Different Wavelengths Requires Different Photoresist Chemistry

436/365nm Novolak Resin	248nm ESCAP	193nm Methacrylate Resin	13.4nm Polymer-Bound PAG Methacrylate Resin
			
436/365nm DNQ PAC	248nm TPS PAG	193nm TPS PAG	
	 triphenyl sulfonium camphor-10-sulfonate	 triphenyl sulfonium perfluorobutane sulfonate	

Resist Transparency dominates earlier wavelengths
Acid Diffusion dominates EUV CA resists
Attaching PAG anion is a clever way to reduce diffusion but adds polymer complexity

Concept: Polymeric-bound PAG [PBP]



Polymer-bound PAG Resist Concept

Benefits of Polymer-bound PAG Approach

- Limits PAG outgassing: covalent attachment of PAG to polymer reduces small molecule evolution from Resist
- Allows Effective Higher Loading of PAG without aggregation or phase separation
- Forces a more uniform distribution of PAG in the resist film
- By attaching the PAG anion to the lithographic polymer, photoacid diffusion is limited by polymer chain mobility
- Can be used in 193nm, EUV, or ebeam lithography for ultra-high resolution where throughput is an issue

THE NEXT CHALLENGE: EUV

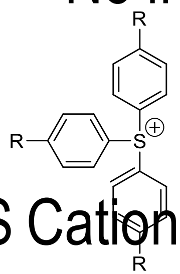
Critical Challenges for EUV Resists

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, acid blur
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 RESIST OUTGASSING

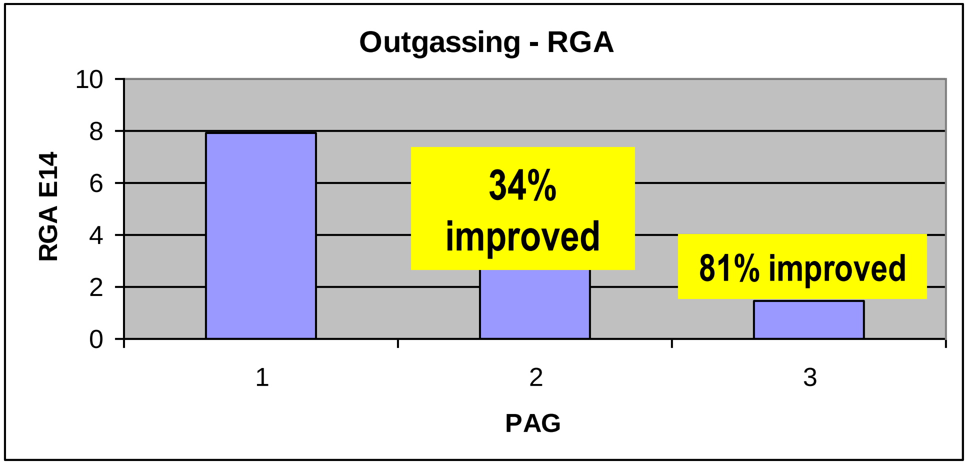
EUV Fundamental Studies - Outgassing

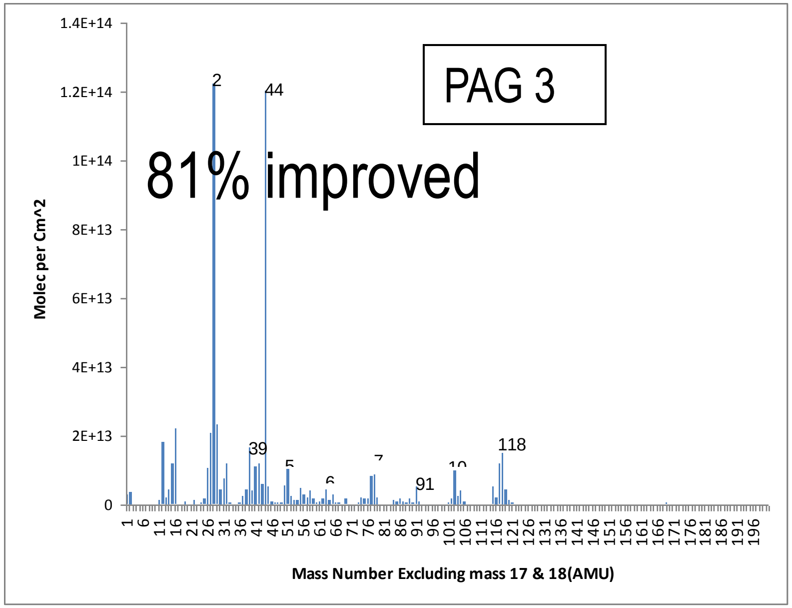
- Reduced Outgassing
  - Cation change reduces outgassing 4x
  - No DPS fragments (186amu)
  - No fragments from ~120-200amu



TPS Cation

New PAG Cations



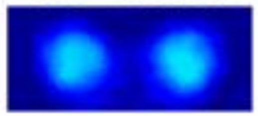


Outgassing and Contamination

Ellipsometry	X-Ray Photoelectron Spectroscopy (XPS)	RGA

MET-2D

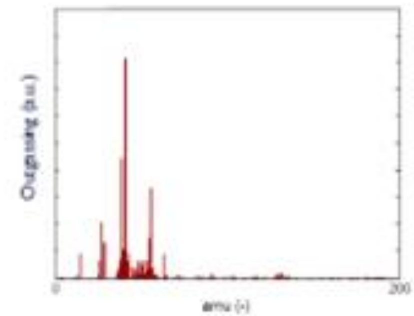
BG resist



ADT cont.
thickness ~0.1nm

	BG	Res
C	100%	100%
S	0%	0%

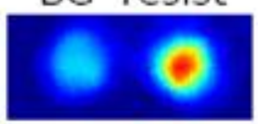
Isobutene, and probably also SO_2 do not contribute significantly to resist related contamination



TPS is problematic

'High contaminating resist'

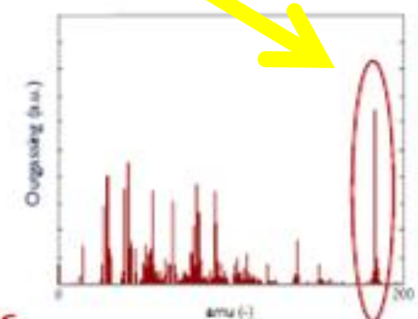
BG resist



ADT cont.
thickness ~1.4nm

	BG	Res
C	100%	98.5%
S	0%	1.5%

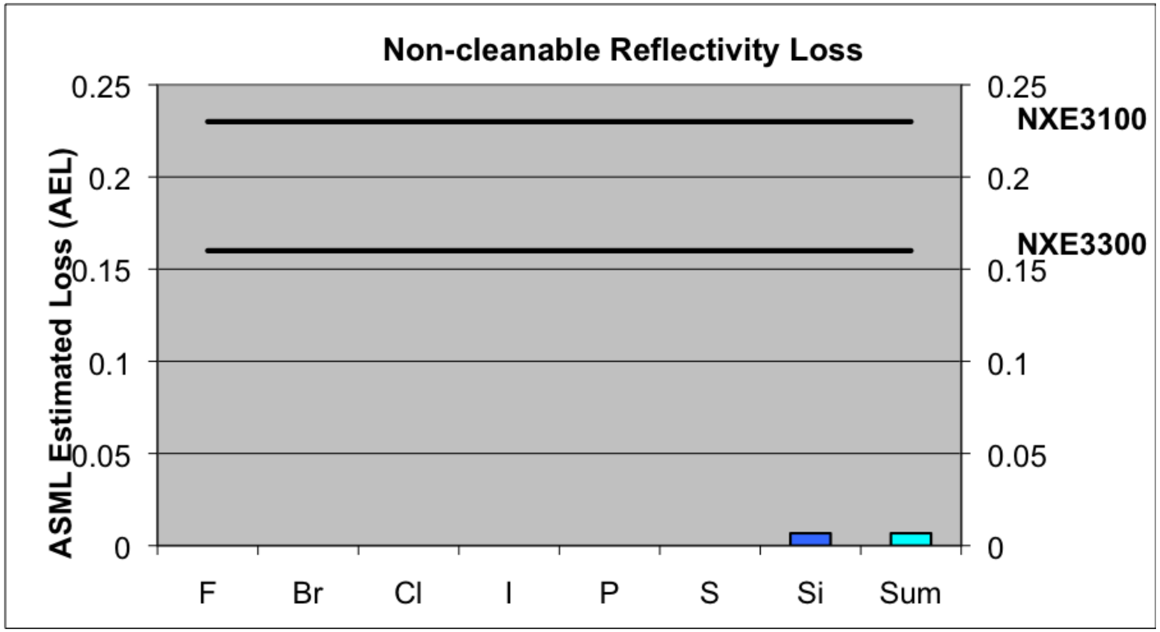
Sulfur containing PAG cation seems to play key role in contamination



-Sublimation and condensation results in contamination of optics and mask

-Expensive – much more expensive than 193 and 248 tools

Witness Plate Results



- Extremely low reflectivity loss after atomic H cleaning
- Low Diffusion PBP Resist meets the NXE requirements

OUT-OF-BAND RADIATION

Out-of-Band (OOB) Radiation Problem

LPP Sn-based Source

- EUV Sources Emit Electromagnetic Radiation from 100 -300 nm wavelength
- From the graph, 200nm energy

  ~8x-15x less than 100nm energy
- Most if not all resists for EUV use PAGs that are designed for 193nm and 248nm exposure
- Could the OOB radiation cause thickness loss at the top of resists?
- Could OOB radiation cause LWR?

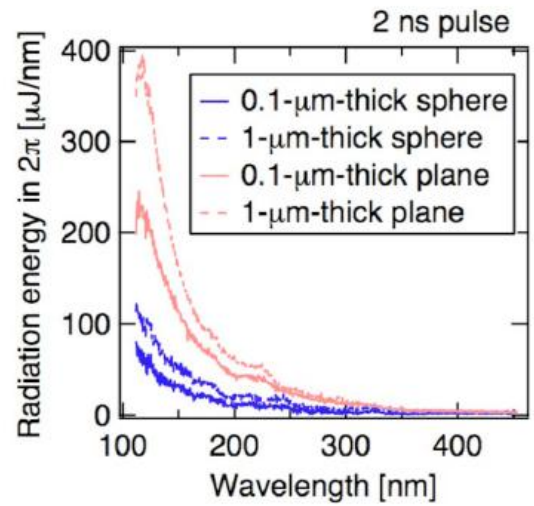


FIG. 3. (Color online) Measured OOB spectra (130–400 nm wavelengths) for a 2 ns laser pulse. The targets were 1-μm- and 0.1-μm-thick Sn planes and spheres.

APPLIED PHYSICS LETTERS **92**, 111503 (2008)

Absolute evaluation of out-of-band radiation from laser-produced tin plasmas for extreme ultraviolet lithography

Hirokazu Sakaguchi,[1] Shinsuke Fujioka,[1,a)] Shinichi Namba,[2] Hajime Tanuma,[3] Hayato Ohashi,[3] Shintaro Suda,[3] Masashi Shimomura,[1] Yuki Nakai,[1] Yasuko Kimura,[1] Yuzuri Yasuda,[1] Hiroaki Nishimura,[1] Takayoshi Norimatsu,[1] Atsushi Sunahara,[4] Katsunobu Nishihara,[1] Noriaki Miyanaga,[1] Yasukazu Izawa,[1] and Kunioki Mima[1]
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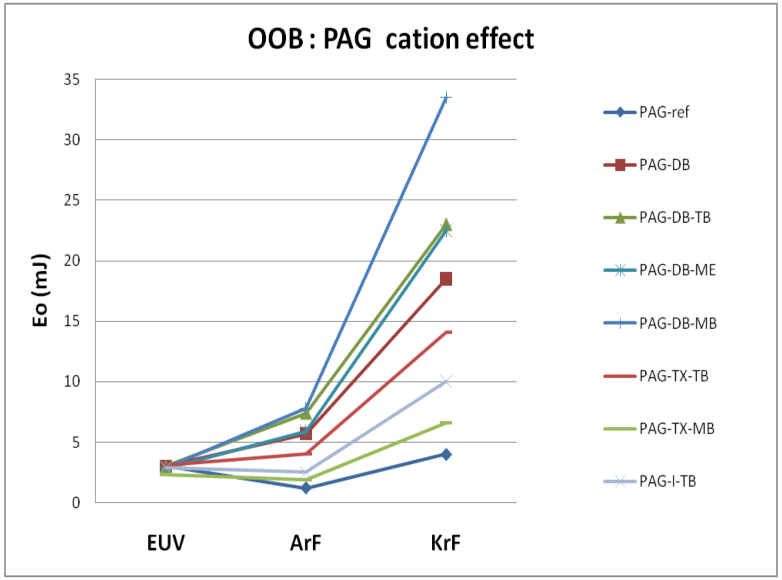
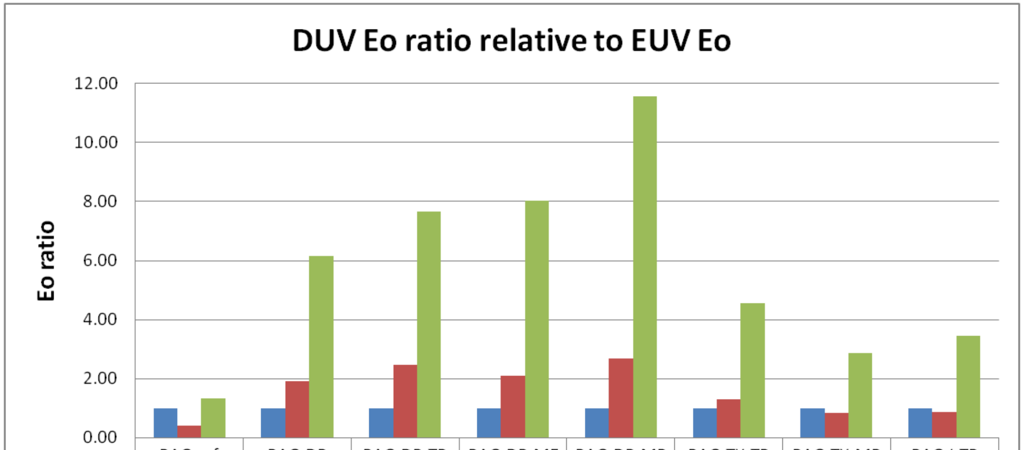
Recent Improvements on OOB - Improved PAG Design





	PAG-ref	PAG-DB	PAG-DB-TB	PAG-DB-ME	PAG-DB-MB	PAG-TX-TB	PAG-TX-MB	PAG-I-TB
EUV	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
ArF	0.40	1.90	2.47	2.11	2.69	1.29	0.83	0.86
KrF	1.33	6.17	7.67	8.04	11.55	4.55	2.87	3.45

- **>15 New PAGs were Screened for OOB**
- **Identified Several New Promising Candidates for Formulation Optimization**
- **These improvements will be Incorporated Future Litho DOEs**

LWR IMPROVEMENT

How to Reduce EUV Acid Uncertainty [true source of LWR]?

DOW®

(Assume dose is held constant)

Increase PAG Loading

$$\frac{\sigma_h^2}{\langle h\rangle^2} = \frac{1}{\langle h\rangle\langle n_{0-PAG}\rangle} + 1.07\left(\frac{(1-\langle h\rangle)\ln(1-\langle h\rangle)}{\langle h\rangle}\right)^2 \frac{1}{\langle n_{photoelectrons}\rangle}$$

Increase Photoelectron Generation Efficiency

$$\langle n_{photoelectrons}\rangle = \phi_e \langle n_{photons}\rangle\left(1-e^{-\alpha D}\right)$$

Increase Absorption

$$\langle h\rangle = 1 - e^{-C\langle E\rangle}$$

Increase C

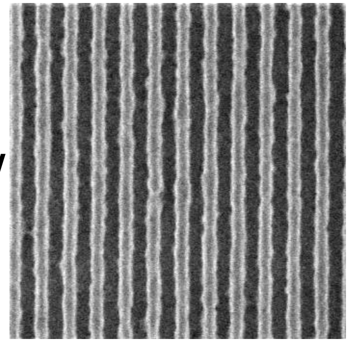
Mack, Thackeray, Biafore, Smith, Proc. SPIE **7969**, 796919 (2011)

What Stochastic modeling tells us about EUV Resist Improvement

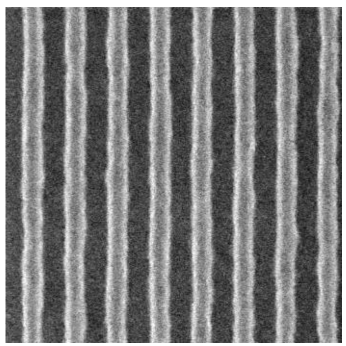
- Shorten Acid Diffusion Length
- Increase PAG Loading (density)
  - Higher PAG density leads to higher sensitivity which means more quencher which is good for LWR
- Increase Photoelectron Generating Efficiency
  - Use polymer matrix that easily yields electrons (Low electron affinity polymers)
- Increase Resist Absorption
  - Use fluorinated monomers, use methacrylate monomers (only 20% EUV photons absorbed at 40nm FT)
- Increase C(acid yield)
  - Improve EUV response of PAG vs OOB response
  - Attach electron accepting groups to PAG

Increasing PAG density

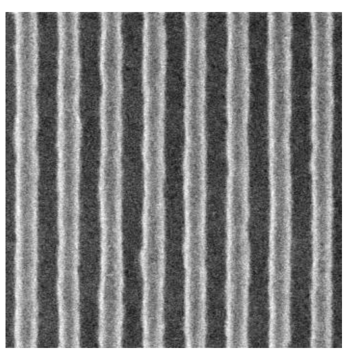
Low PAG density
LWR = 5.2nm



Med PAG density
LWR = 3.8nm



High PAG density
LWR = 3.1nm



25nm 28nm 30nm

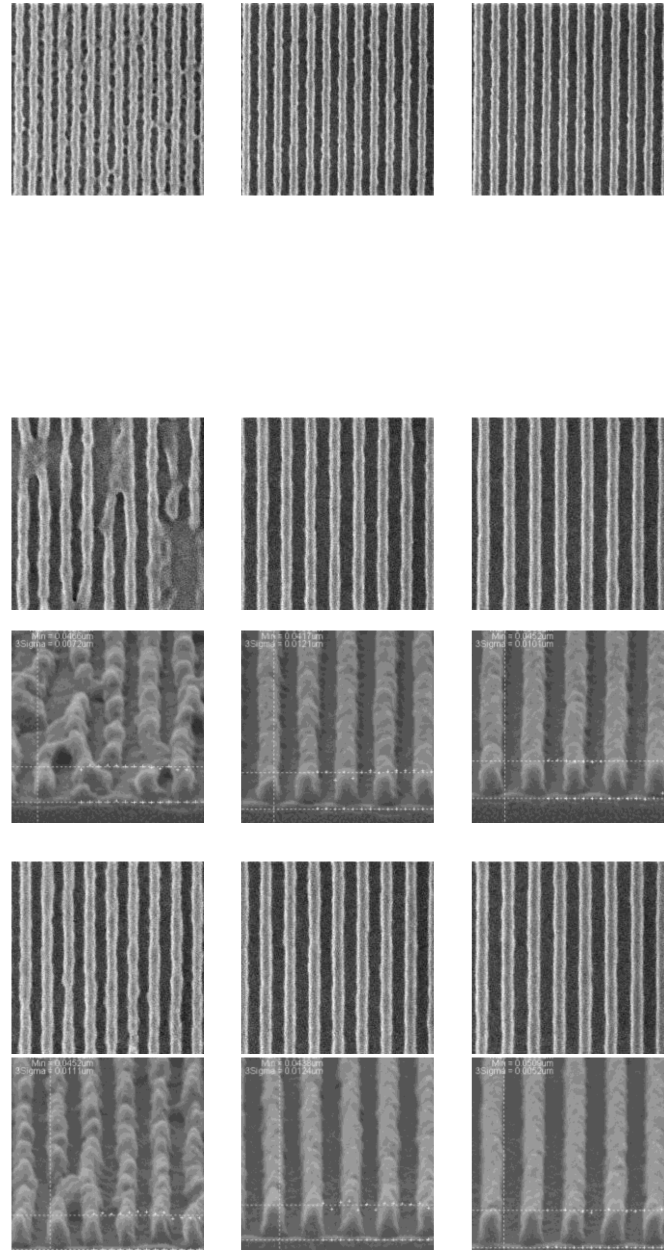


Image Log-Slope and Exposure Latitude

- For an infinite contrast resist,

$$\frac{\partial \ln E}{\partial CD} = \frac{1}{2}\frac{\partial \ln I}{\partial x}$$

- For example, for a ±10% CD specification,

$$\%\ \text{Exposure Latitude} \approx 10{*}\text{NILS}$$

(where it was assumed that NILS is about constant over the ±10% CD range)

Ref. C. Mack, "Fundamentals of Optical Lithography"

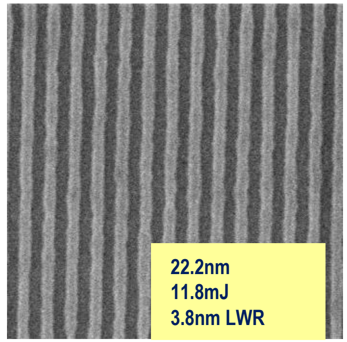
Dipole Data of Low Diffusion Resist

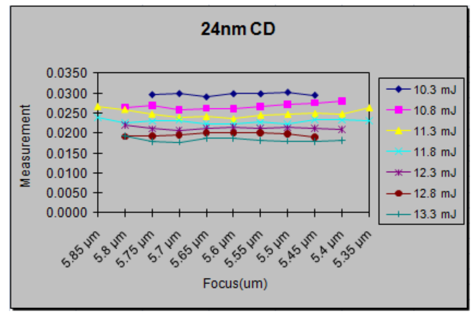
eMET (11.8mJ)

Resist:
Resist Film Thickness=450Å
SB=130°C/90s; PEB=100°C/60s
ARC: UL B

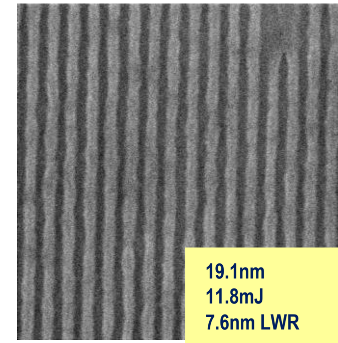
EXP: eMET Albany
NA=0.30; Dipole
Mask; H/V Cleave
DEV: TEL-SMT-30S=**TMAH, 30s**

24nm HP





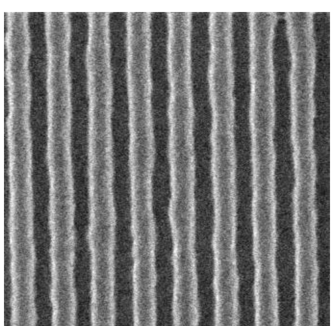
20nm HP



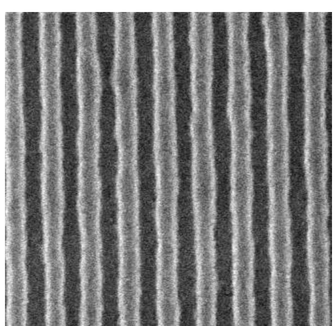
BMET (~16.8mJ)
XU090640BB
SB/PEB 110C/100C
FT=50nm

Acid diffusion length = 8nm

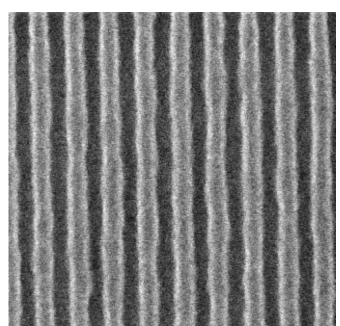
28nm



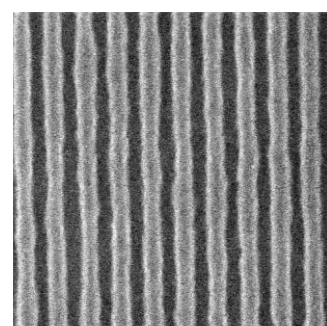
26nm



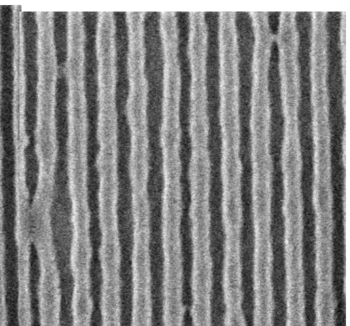
24nm



22nm



20nm

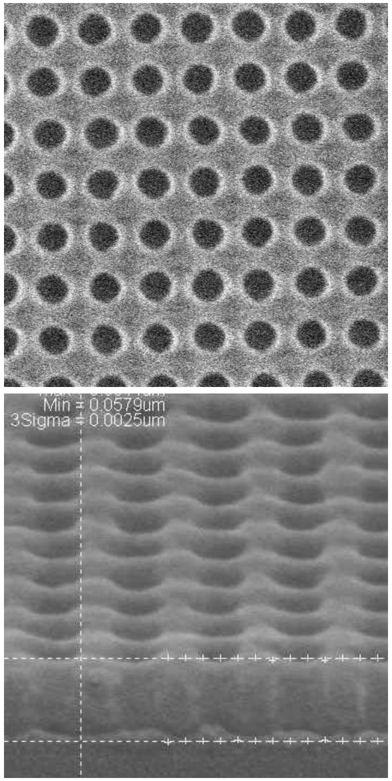


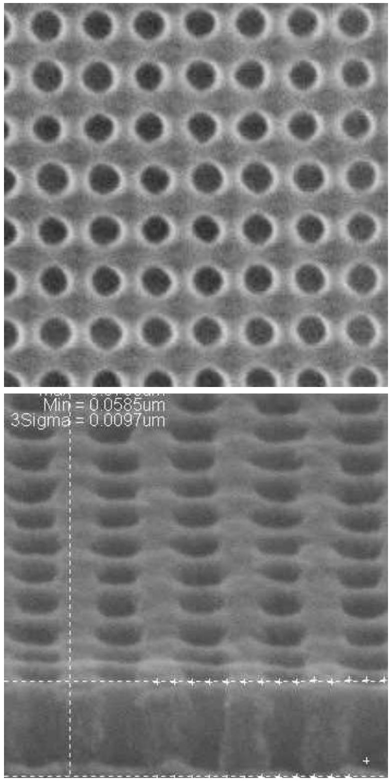
Results of Recent C/H Evaluation at LBNL (30nm 1:1 C/H) Identified Improved Formulations

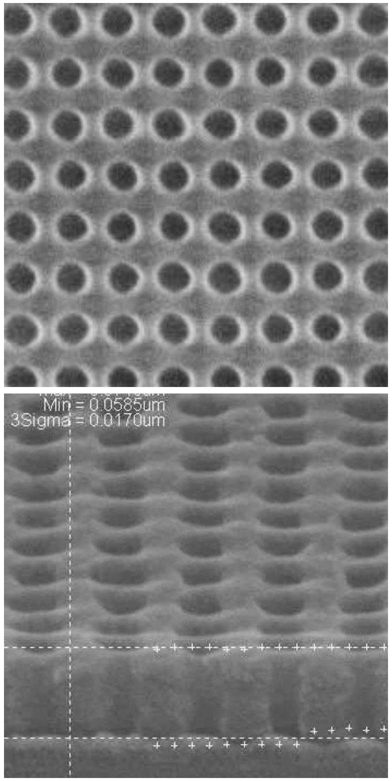
MA

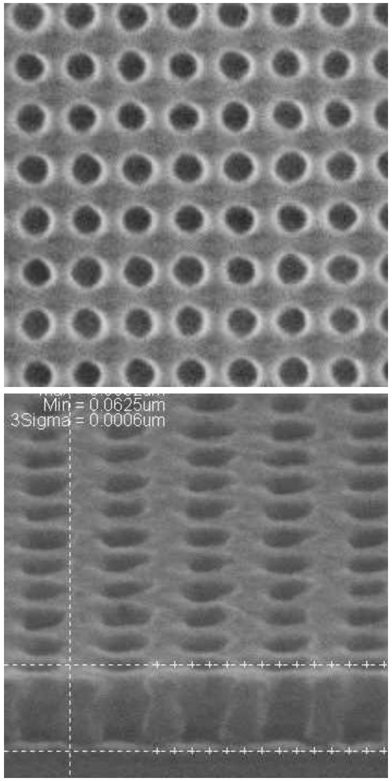
DOW

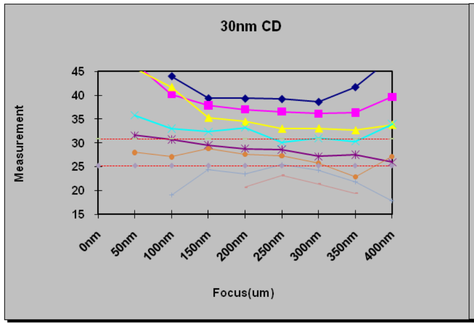
Control	Sample-A	Sample-B	Sample-C
1.74nm CDU(5 die avg)	1.44nm CDU(5 die avg)	1.54nm CDU(5 die avg)	1.44nm CDU(5 die avg)

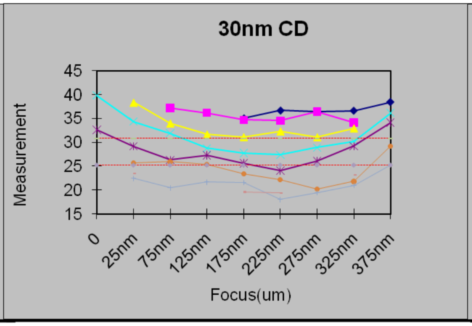


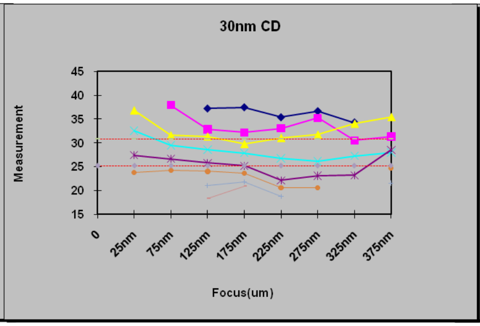


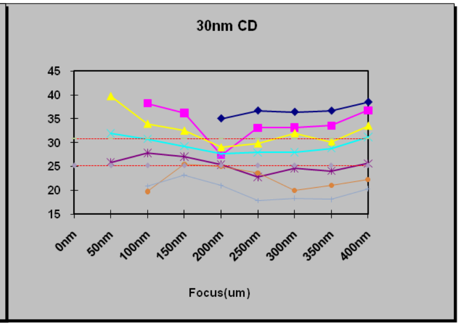










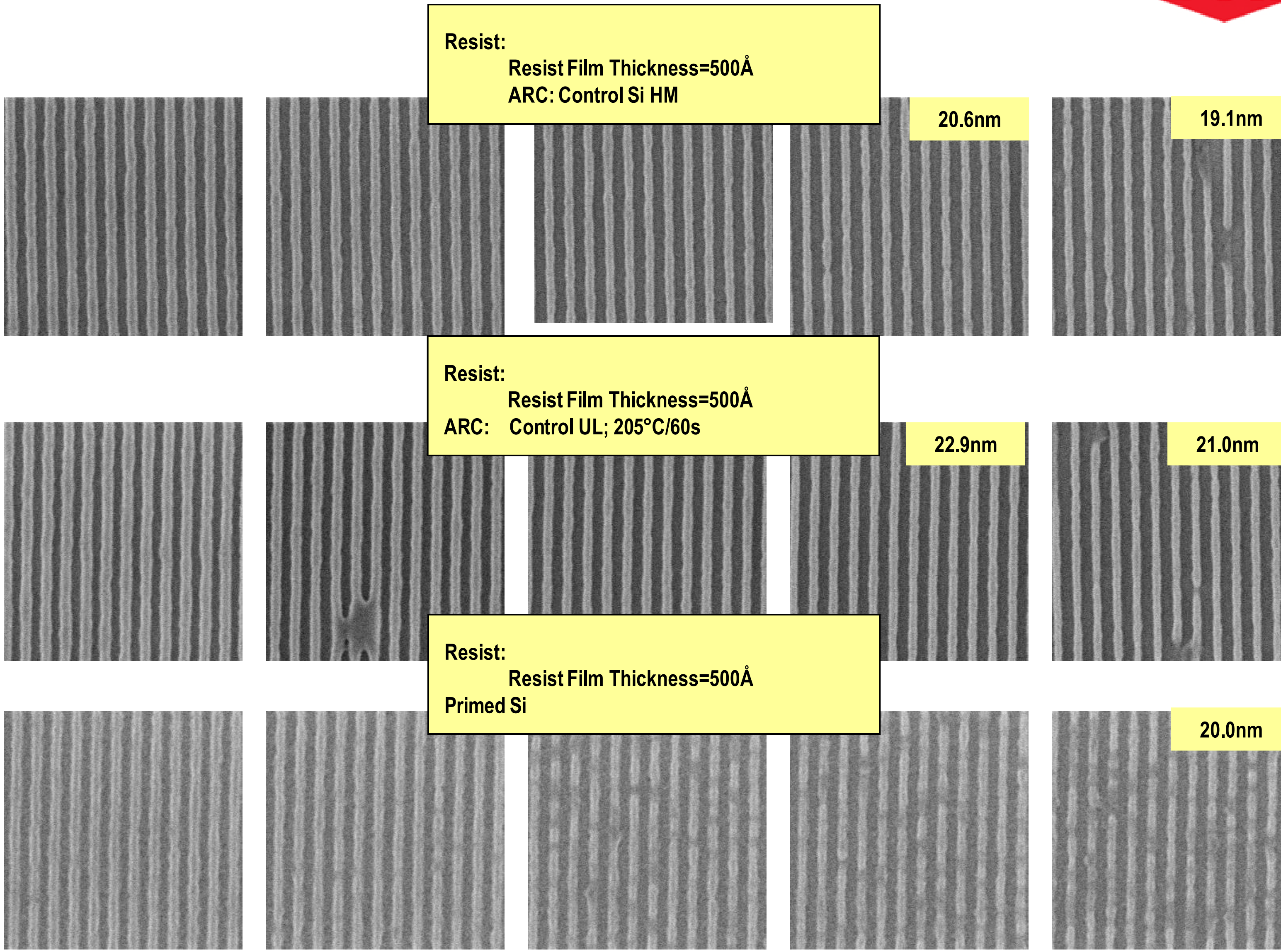


EUV RESIST SUBSTRATE DEPENDENCE

Substrate Choice for EUV Resist

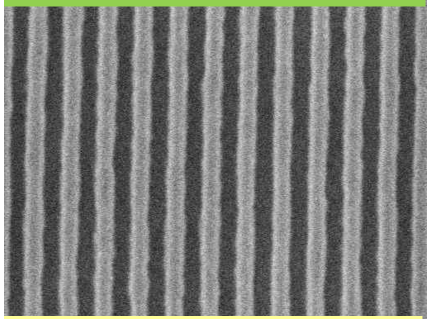
- Silicon HM material
  - » Advantages: good for etch integration, use ArF formulations to help with OOB minimization
  - » Challenges: Resist poisoning, stability, surface energy matching, developer penetration, CTE
- Organic UL
  - » Advantages: universal substrate, chromophore inclusion for OOB minimization, ultrathin coatings possible
  - » Challenges: etch selectivity, surface energy matching, CTE
- Direct on Substrate
  - » Advantages: reduced coat steps
  - » Challenges: individual resists for different substrates [resist complexity], no OOB minimization, etch recipe optimization

28nm HP Overexposure Margin 50nm FT
(Si HM, ORG UL, Primed Si)



Low Diffusion Resist Performance on Si-HM vs Organic UL

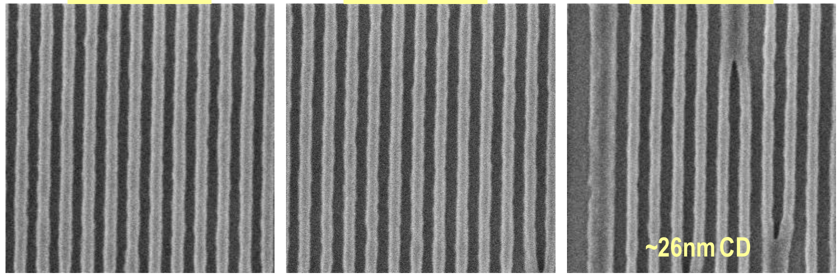
(70nm FT)

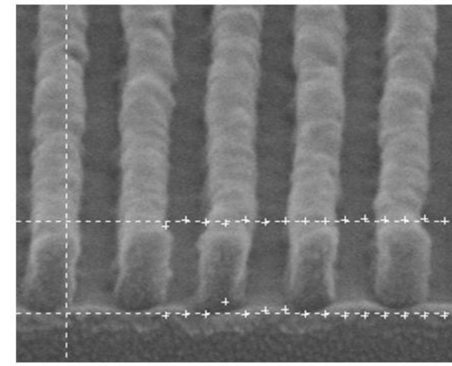


27.9nm/13.4mJ/3.6nm LWR

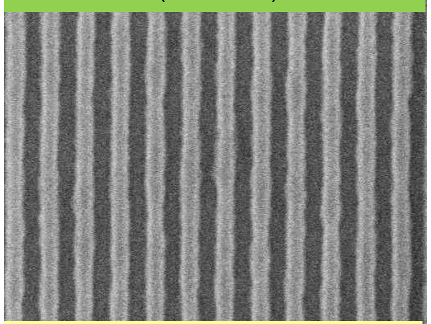
Organic UL

-5% | 13.35mJ | +5%





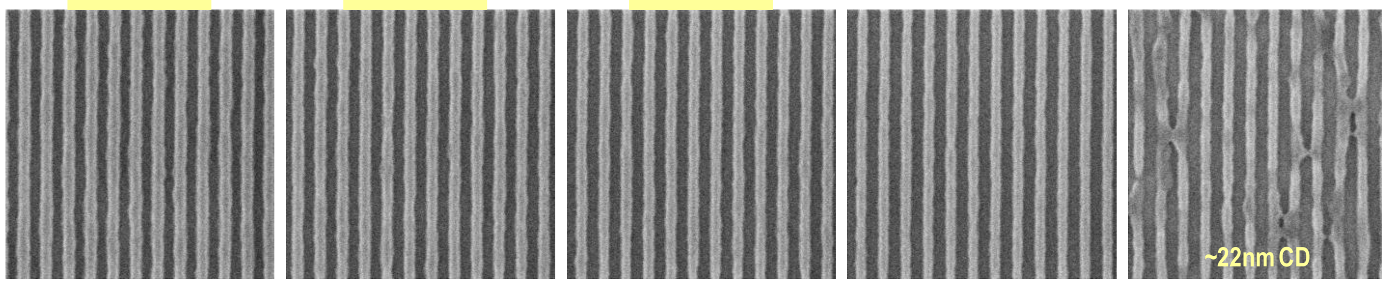
(70nm FT)



26.9nm/13.4mJ/3.2nm LWR

on Si Hardmask

-5% | 13.35mJ | +5%

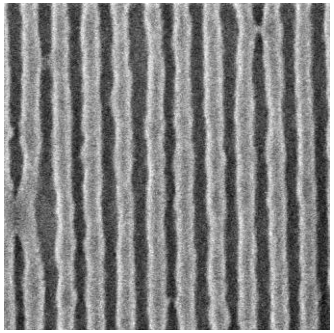


EUV, EBEAM AND 193 CAPABILITY OF PBP

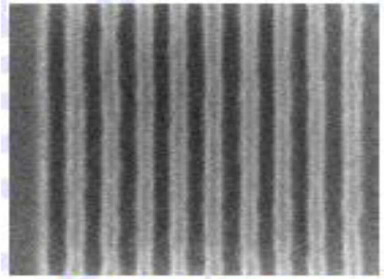
Prospects for the Future
Ultimate Resolution of PBP CA resist

Ultimate Resolution of EUV PR with e-Beam

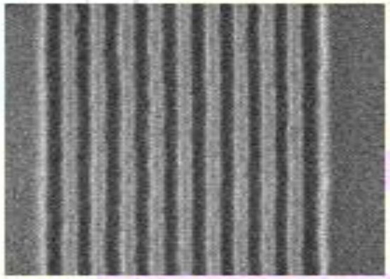
- 15nm hp Resolution with PBP Platform



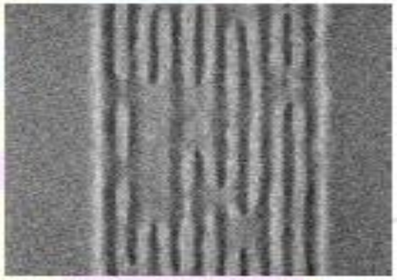
EUV dipole
20nm hp



25nmhp-Dose n°18



20nmhp-Dose n°18



15nmhp-Dose n°18

193 annular
38nm hp

Not resolution limited—
Pattern Collapse limited!

EUV Resist Development Status

- PBP-based resist remains the lead candidate for EUV lithography
- Steady progress in acid yield, absorbance, OOB, outgassing, substrate optimization continues
- Steady progress in LWR continues
- Resolution is currently 19nm hp by EUV, 15nm hp by ebeam---limited by pattern collapse and LWR not resolution!!
- Source improvements will improve stochastic effects leading to better resist performance
- Optics and mask improvements will improve aerial image leading to better resist performance