2H'08 IEUVI Resist TWG Optimizing RLS

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Presentation Overview

- Intel Lithography Requirements
- EUV Patterning Mechanism
- RLS + Quantification of Improvement
- 2008 EUV Photoresist Progress / Status
  - EUV Sensitization = Higher AGE
  - Guest/Host → Polymer-bound PAGs = Homogeneity + Reduced DL
- Ways to Improve / “Cheat” RLS
  - Underlayers / Multilayer Film Stacks = Improved Resolution + DOF
  - Ancillary Chemicals + Post-processing = Reduced LWR → New Champ
  - *Photoresists with Increased Absorption = Higher H^+ yields*
  - *Higher Quantum Efficiency PAGs = Higher AGE*
  - *Molecular Glass Resists = Homogeneity + Reduced pixel size*
- “RLS + OR” – Can’t Forget Resist Outgassing
  - Negative-tone photoresists = Good patterning w/ lower OR?
- Recommendations / Next Step

intel

Intel Critical Litho Roadmap

MPU Node	Potential Approaches	HVM Timing
32 nm	193nm ≥ 1.2NA	2009
22 nm	193nm ≥ 1.30NA DP or "SE" w/ Low k1	2011
16 nm	**EUV ≥ 0.25NA** or 193nm ≥ 1.30NA DP	**2013**
11 nm	EUV > 0.25NA or TBD	2015

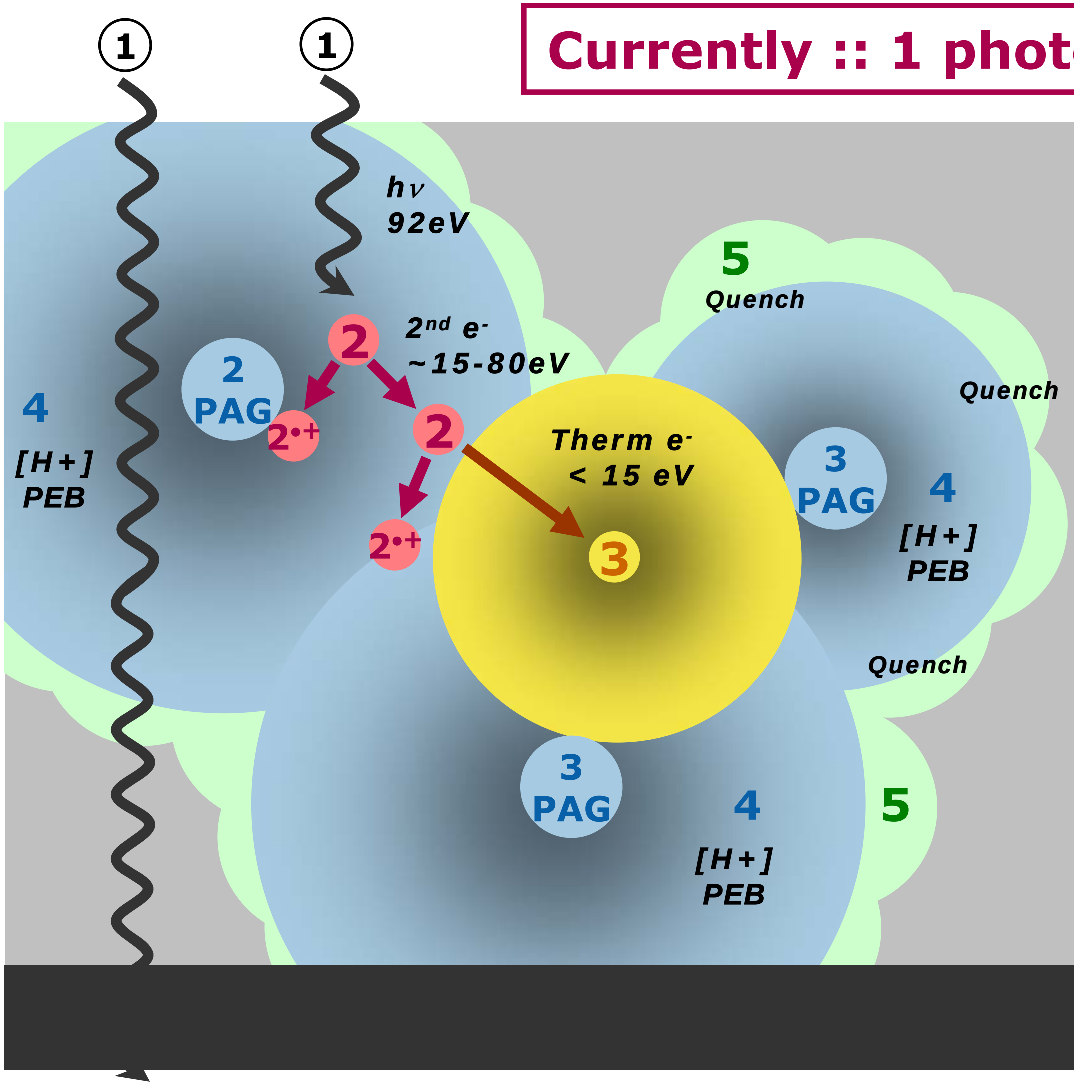
- Half Pitch Scales ~0.7x per Generation from 45 nm Node @80nm HP
- Intel will Continue to Monitor all Emerging Lithography Technologies

➥ EUV Readiness Requires 32 nm HP and Below

LWR < 10% of FCCD; E_{size} < 10mJ/cm^2

Mechanism for EUV Chemically Amplified

Currently :: 1 photon → ~4-8 2nd e⁻s → Φ~2-4



Anisotropic

[1] Photon Absorption

[2] Matrix Ionization

Isotropic

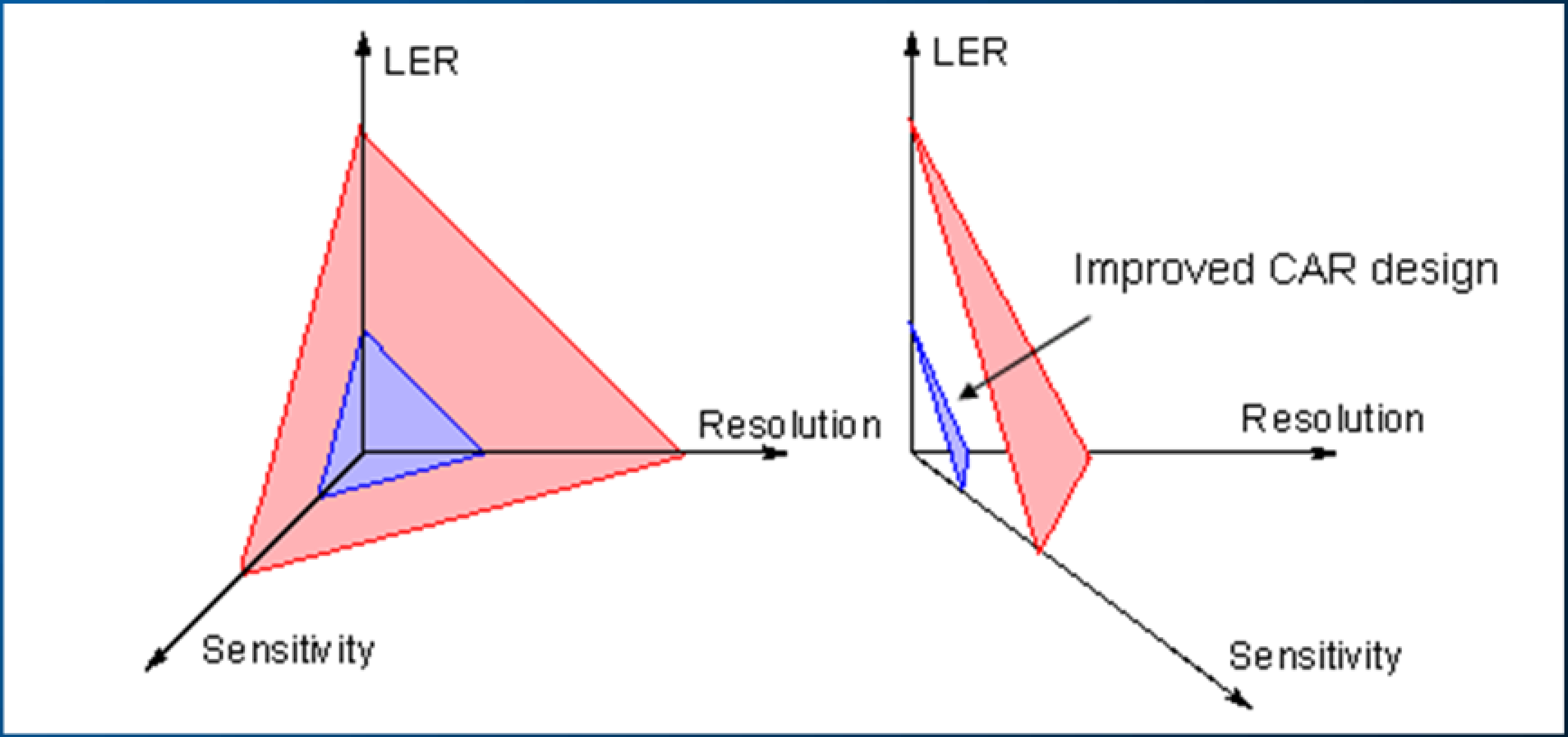
[3] PAG Activation by Thermal Electrons

[4] Acid Diffusion / Deprotection / Quenching

[5] Develop

Tagawa, Kozawa, Gallatin, Brainard, Fedynyshyn, etc

RLS Tradeoff



- RLS limitation is intrinsic to CARs → must reduce material *constant* through improved design

⇘Z-factor is easy way to quantify material constant……

Z-Factor[1] = Quantitative Resist Comparison

$$\text{Z-FACTOR (mJ*nm}^3) = (\text{RES})^3 * (\text{LER})^2 * (\text{SEN})$$

$$nZ_{32} = \frac{\text{Material Z-Factor}}{\text{32 HP Target Z-Factor}}$$

	CD (nm)	MIN LWR 3s (nm)	ESIZE (mJ/cm2)	Z-FACTOR (mJ*nm3)	nZ_{32}
32 HP Target	32	2.00	10.00	6.6E-09	1.0
Intel Q4'08 Goal	30	4.00	7.50	1.6E-08	2.5

PRO

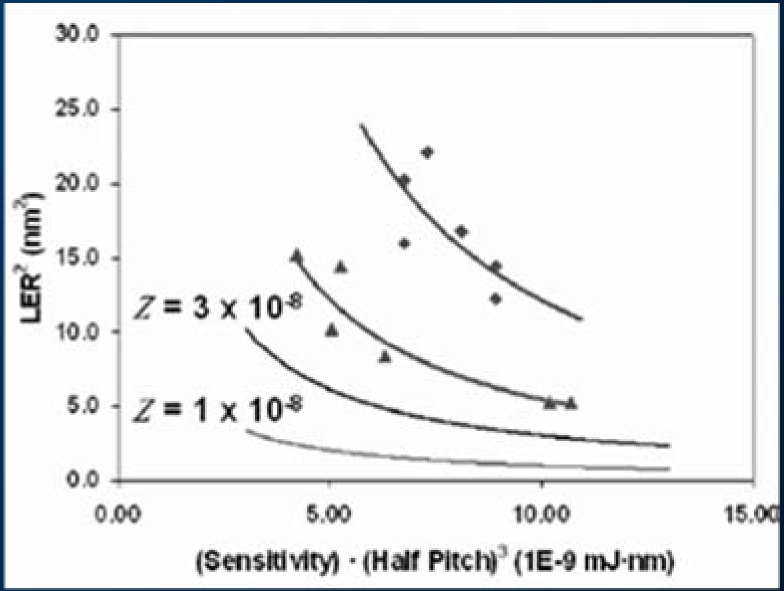
• Simplified approach where limiting resolution becomes proxy for experimentally measured resist blur

• Easy to remember, quick calculation, quantifies improvement

• Plugs into existing infrastructure

CON

• Simplification results in exposure-tool / illumination-dependent Z-factor since NILS term is not accounted for…..



[1]Wallow, et al SPIE 69211F (2008)

Intel Benchmarking All EUV resists using Z-factor (or nZ_{32}) Moving Forward

Intel MET :: Experimental Conditions

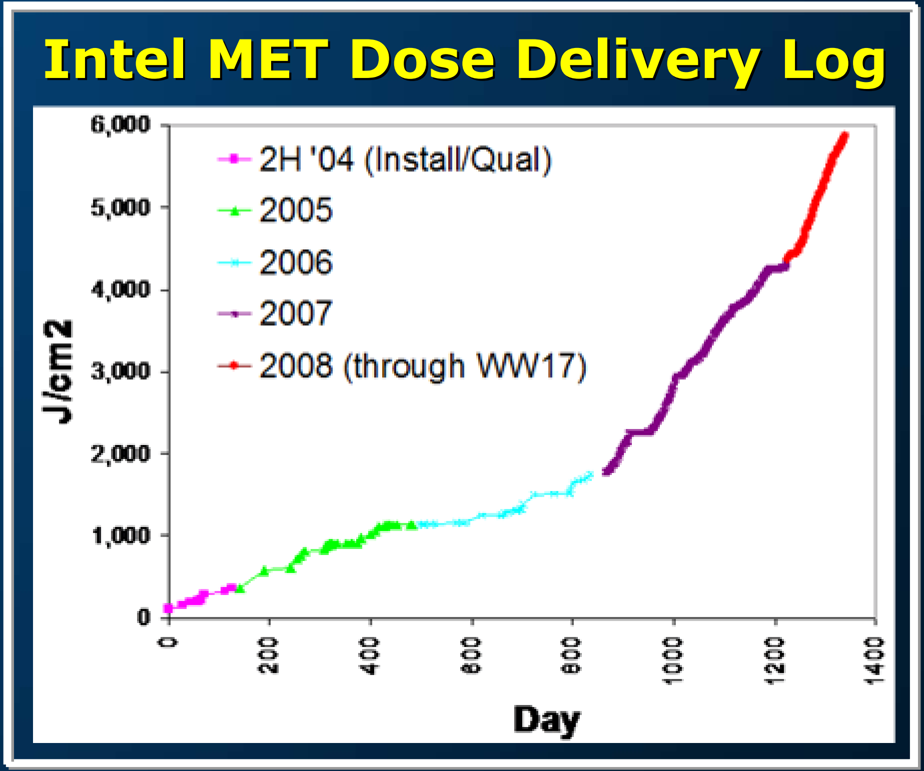
- λ = 13.5 nm
- 0.3 NA with 10% Area Central Obscuration
- Annular Illumination (0.36/0.55)
- Low Flare ~ 3 (DF) -6% (BF)
- Field Size = 200 um x 600 um
- Developer = NMD-3
- TOK 1123 E0 ~ 5.90 mJ/cm^2
  (New LBNL/NIST Dose Calibration)

2008 Performance Metrics

- > 85% Uptime
- Delivering ~90 J/cm2/week
  (~50 J/cm2/week in 2007)

> 120 Resists Screened in '08

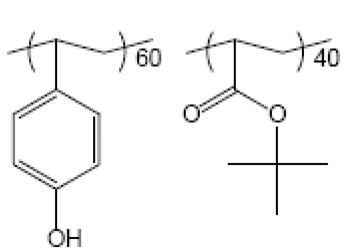
- No Evidence of Measurable Reflectivity Loss in PO
  (Contamination Seen in Illuminator Optics)



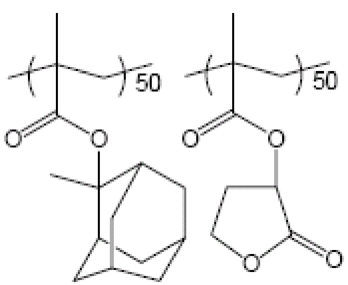
EUVL Allows Diverse Material Options

Novolac	Negative Tone	PHS	Hybrid (PHS-co-Acrylate)	Acrylate	Fluorinated	Polymer - Bound PAG	Molecular Glass
365+	248+	248	248	193, 193i	157, 193i	193+	193+
EUVL							

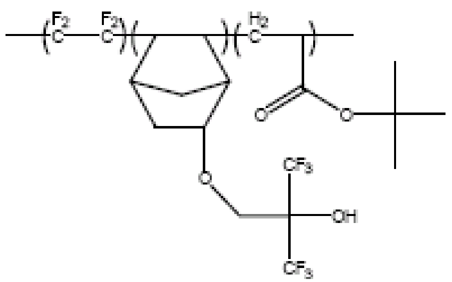
Examples From Literature

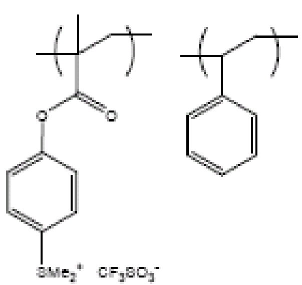


Hybrid Resin



Acrylic Resin

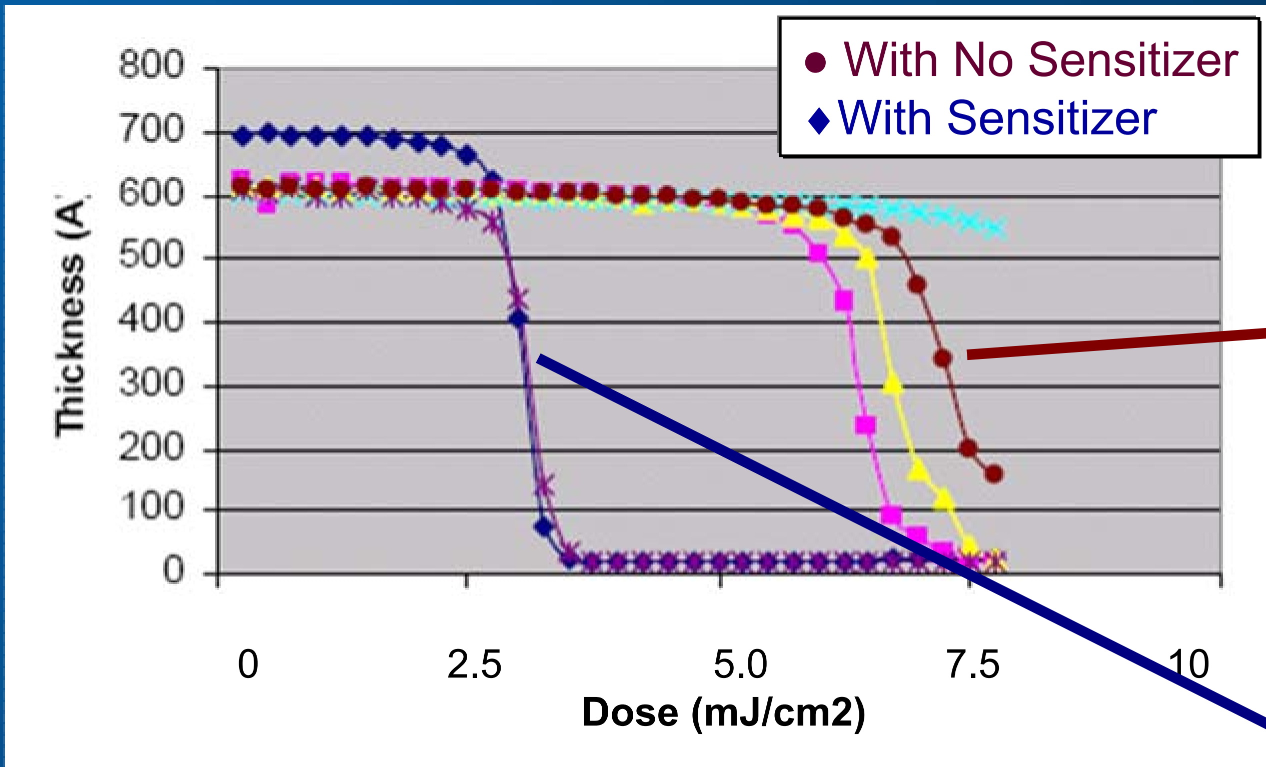

Fluoropolymer


Polymer Bound PAG

- **Focus on Improved Sensitivity and Controlling Blur**

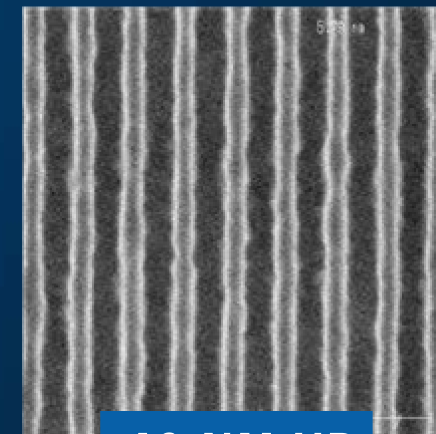
➯ **Academics / Vendors can Reuse Existing Core Competencies (w/ Eye on Continued Innovation)**

EUV Mechanism[2] Provides RLS Gain

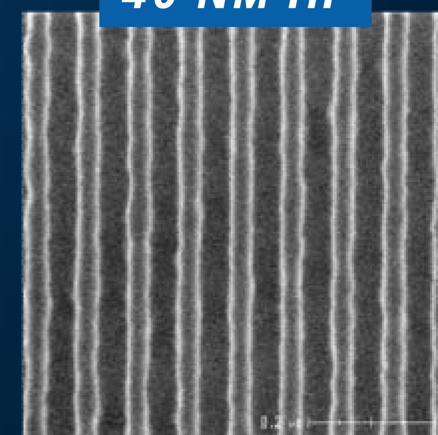


Resist A nZ_{32}~17.7

S=13.8 mJ; L<5.5 nm



40 NM HP



Resist B nZ_{32}~6.3

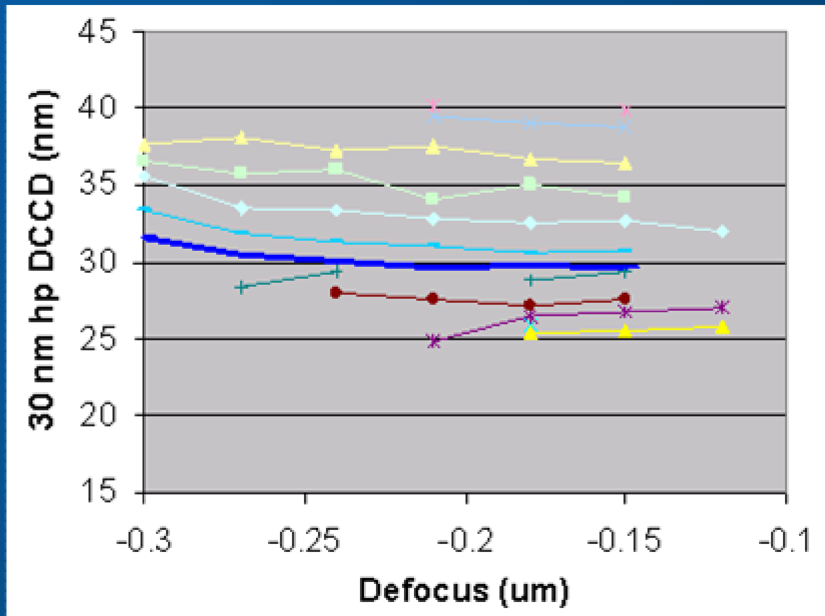
S=7.0 mJ; L<5.0 nm

- **Resist Sensitivity Improved 30-50% via Addition of EUV Sensitizing Agents**
- **No Loss In Resolution or Degradation in LWR**

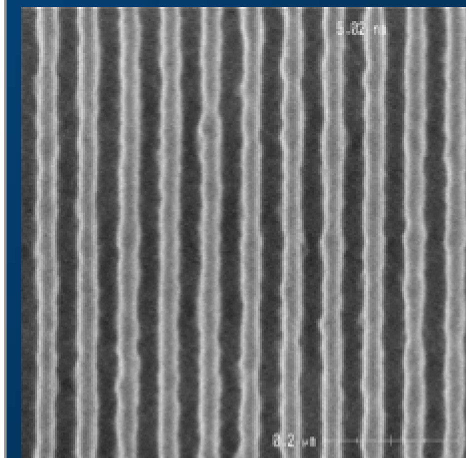
➪ **Multiple Suppliers Achieved Similar Results in 1H'08**

[2]Kozawa, et al. JVSTB 25, 2481 (2007)

Resist C = 1H’08 RLS Fast Champion

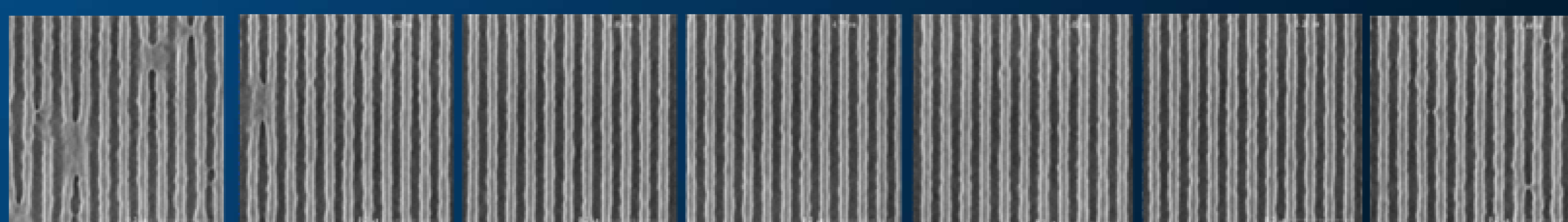


30 nm HP, 4.7 nm LWR, 10.3 mJ/cm²



nZ_{32}~3.7

Defocus (μm)	-0.30	-0.27	-0.24	-0.21	-0.18	-0.15	-0.12
LWR (nm)	NA	7.92	4.68	4.85	4.73	5.24	6.24



Usable DOF > 0.1 μm

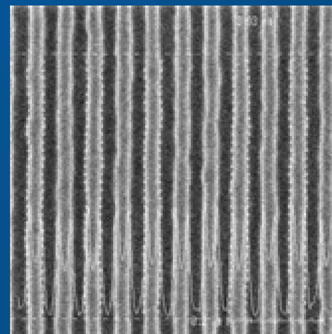
- **Fast Polymer-Bound PAG Platform with Reasonable DOF, EL, and LWR @ 30 nm HP**

Leading EUV Resists = Great Progress 1H'08[1]

Resist B

$E_{size}(34)=7\ mJ/cm^2$
Min LWR = 5.5 nm
(Calc LER ~ 3.9 nm)
$ZF=4.2E\text{-}08\ mJ*nm^3$

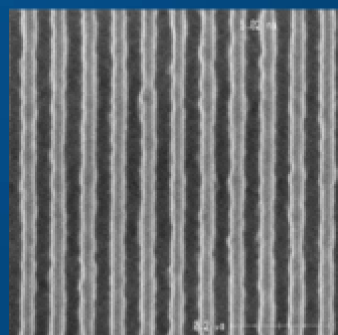
nZ_{32}~6.3



Resist C

$E_{size}(30)=10.8\ mJ/cm^2$
Min LWR = 4.7 nm
(Calc LER ~ 3.4 nm)
$ZF=2.4E\text{-}08\ mJ*nm^3$

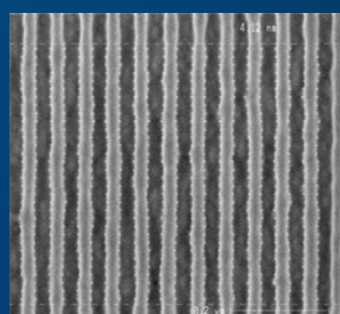
nZ_{32}~3.7

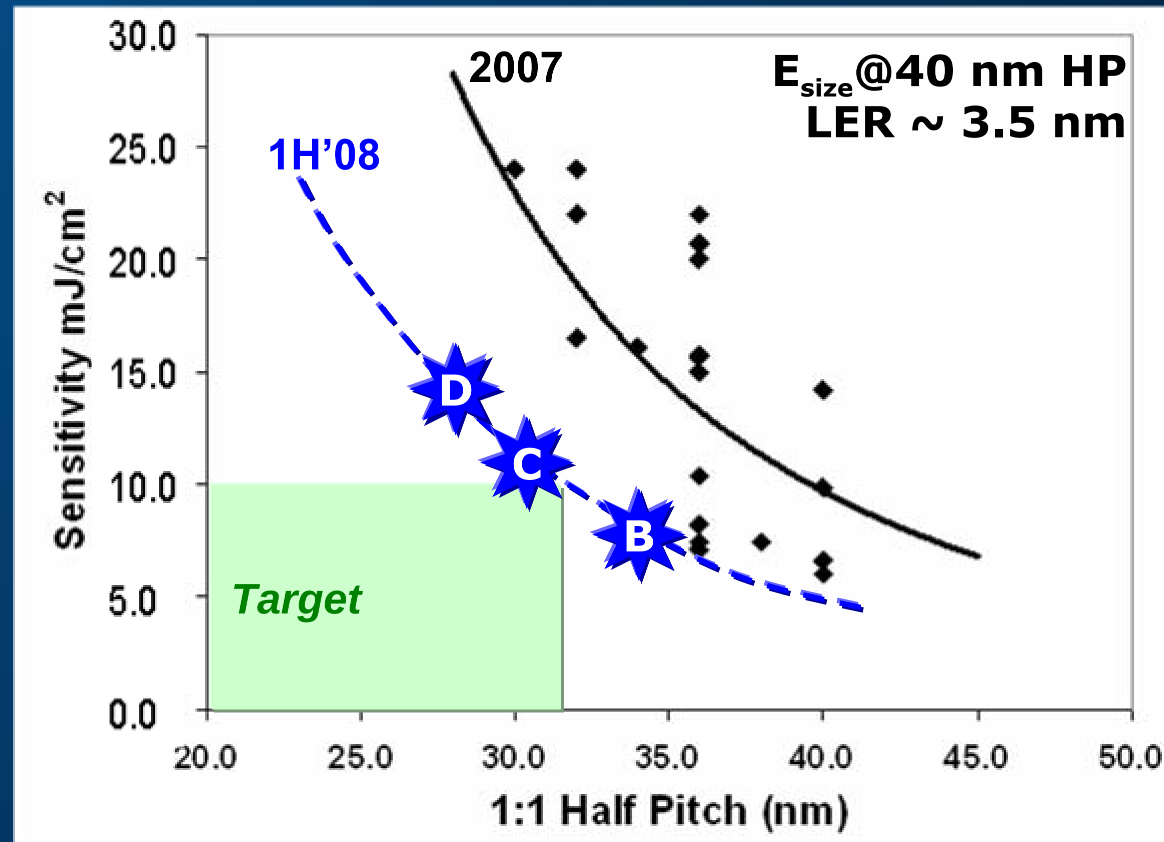


Resist D

$E_{size}(28)=14.3\ mJ/cm^2$
Min LWR = 4.2 nm
(Calc LER ~ 3.0 nm)
$ZF=2.2E\text{-}08\ mJ*nm^3$

nZ_{32}~3.4

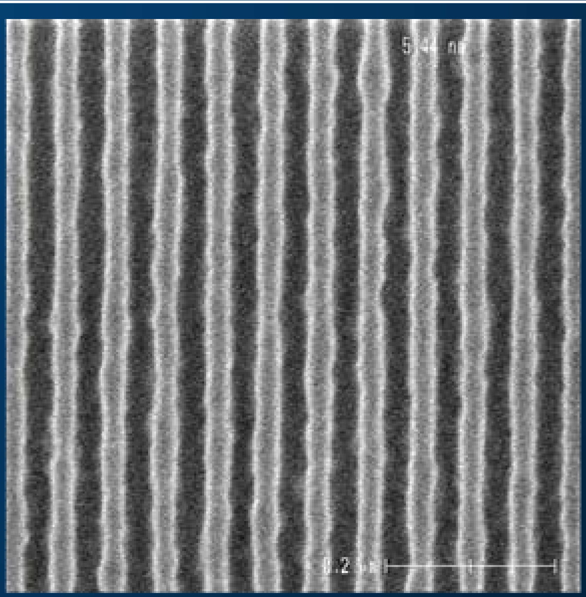




[1]Wallow, et al SPIE 69211F (2008)

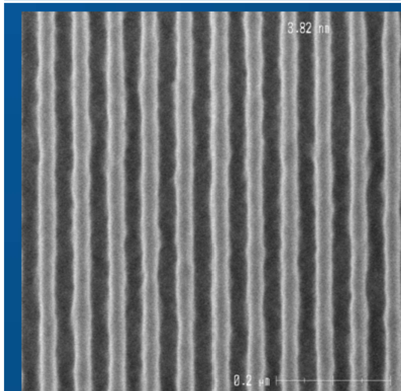
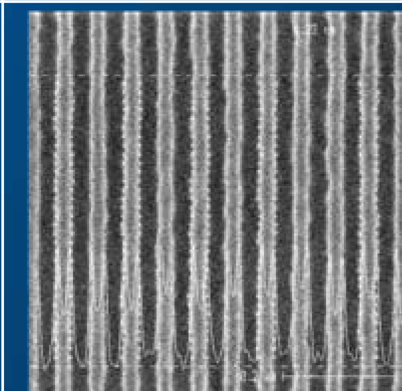
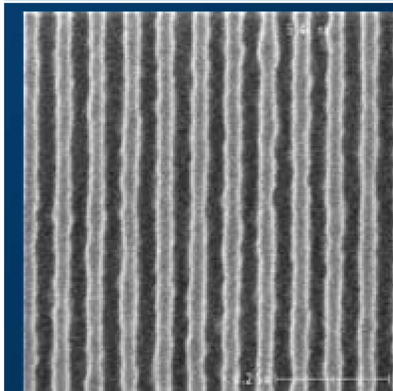
Challenges Remain, but 32 HP Patterning is Looking Viable w/ EUVL + CAR Platforms. Focus on EUV throughput + CAR Extension to 22 HP.

UL Enhances Resist B Patterning to 30 HP

Resist B + Underlayer A	Resist B + Underlayer B
Not Resolved	
Max Res = 34 HP	Max Res = 30 HP
$nZ_{32} \sim 6.3$	$nZ_{32} \sim 5.0$

- **Multi-layer stacks may play a vital role in delivering RLS patterning package that can be integrated.**

Rinse Agent Improves EUVL Manufacturability

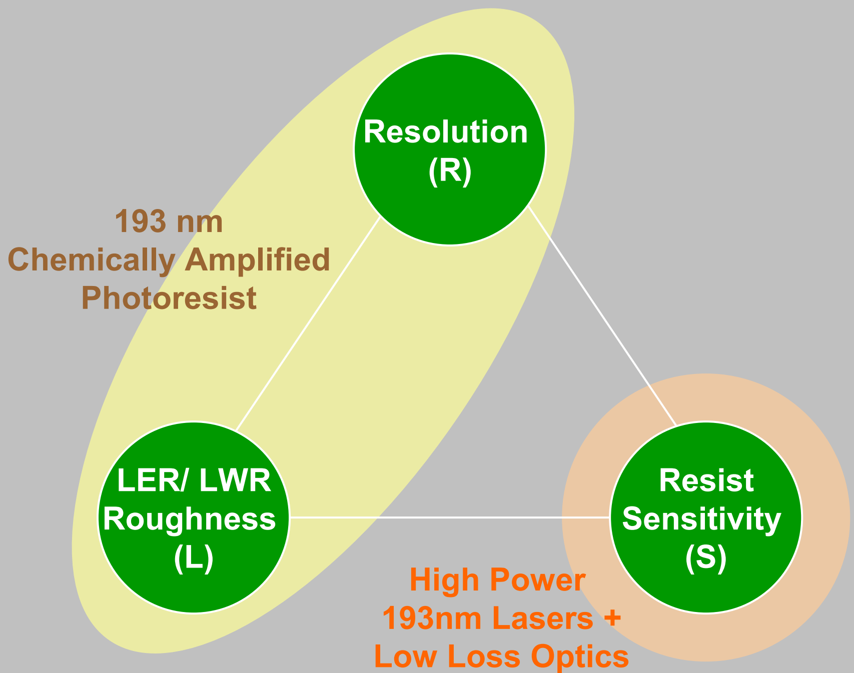
30 nm HP	1H'08 "Smooth" RLS Champs		"Fast" RLS Champion	
	Resist D	Resist C	Resist B	Resist B + Rinse Agent
				
MIN LWR (nm)	3.8	4.3	5.3	26%↓ 3.9
DOSE (mJ/ cm²)	14.0	11.0	8.7	38%↓ 8.7
nZ_{32}	3.4	3.7	5.0	2.7

[1]Wallow, et al SPIE 69211F (2008)

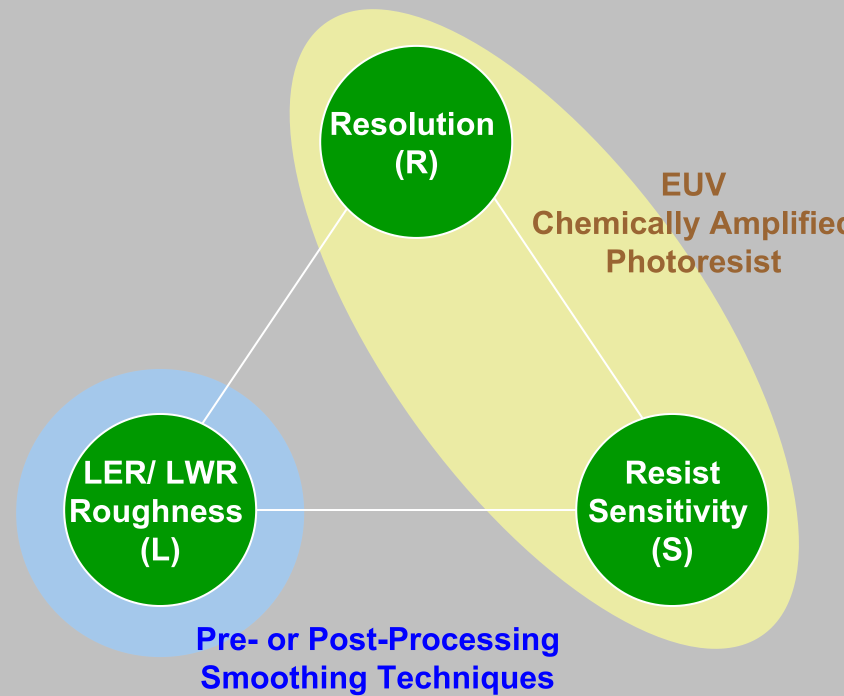
- **Pre- and/or post-processing techniques can significantly improve roughness of high resolution / fast EUV resist.**

➯ **We are evaluating ancillary chemicals that can increase EUV throughput and provide improved patterning.**

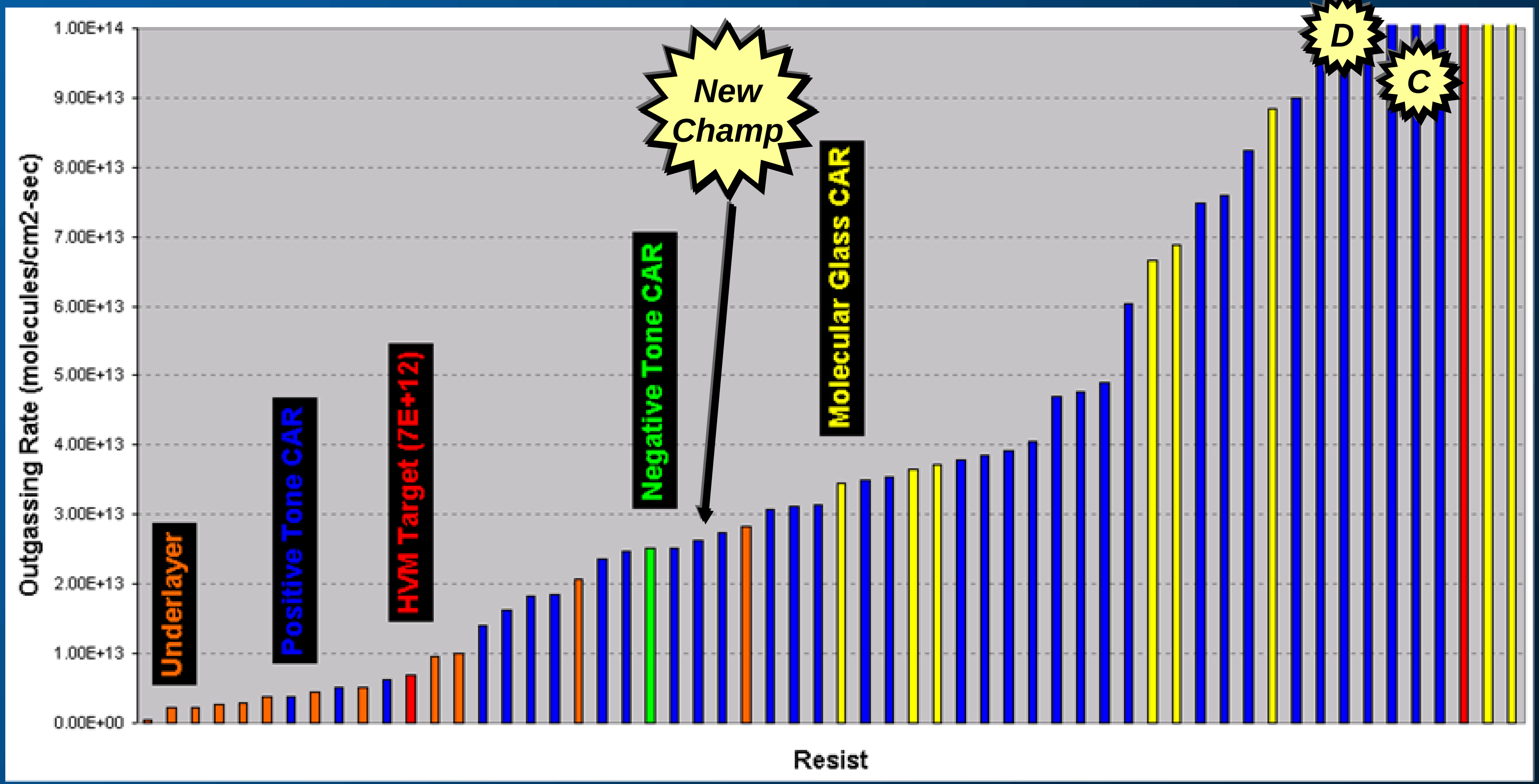
193 Lithography



EUV Lithography



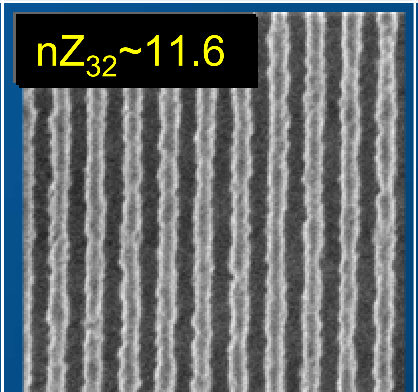
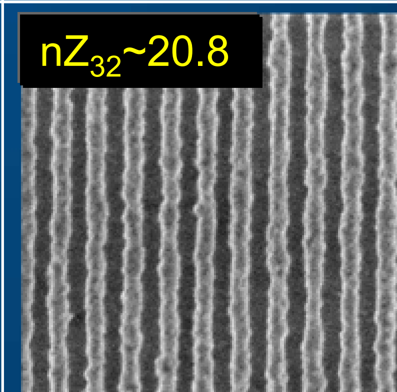
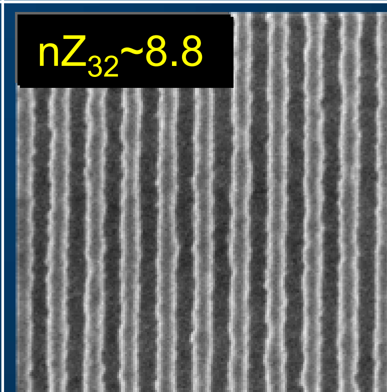
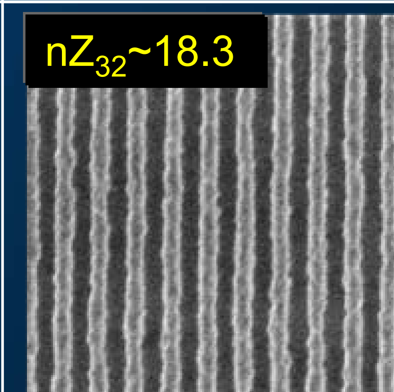
Outgassing Rate for 'Resists' Tested 2008



- Albany ROX data scaled to HVM outgassing rate shows good progress towards meeting HVM target (7E+12).
- Underlayers + negative tone CARs tend to demonstrate lower outgassing rates than positive tone materials.

➯ Significant improvement required to simultaneously meet RLS and OR targets for 32 HP and below.

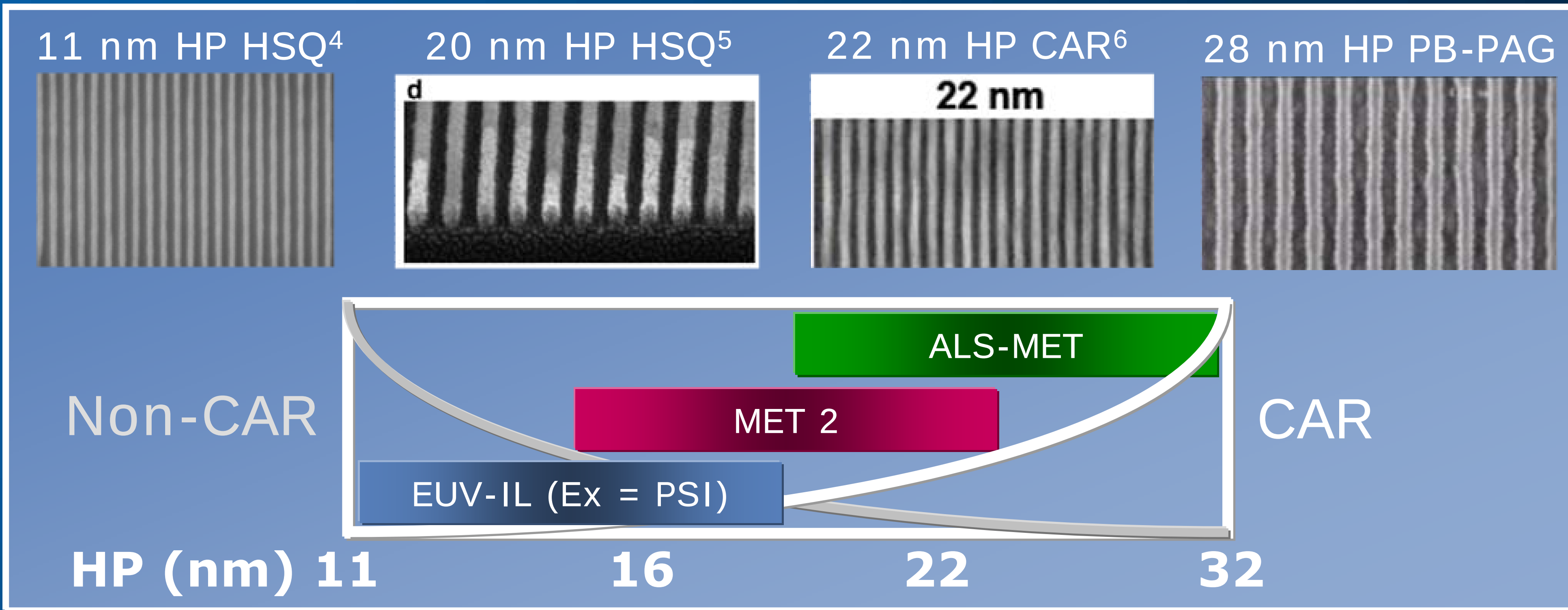
High Performance Negative Tone (Resist F)

32 nm HP	Bright Field Patterning		Dark Field Patterning	
	Positive Tone (Resist E)	Negative Tone (Resist F)	Positive Tone (Resist E)	Negative Tone (Resist F)
				
MIN LWR (nm)	6.5	8.0	5.0	6.2
DOSE (mJ/ cm^2)	11.0	13.0	14.0	19.0

- **Developer = NMD-3**
- **Gap Narrowing Between Positive-(E) + Negative-(F) Tone**
  (Expect better performance under BF / high flare patterning condition)
- **Resist F has Best in Class Outgassing Performance**
  (Albany ROX = 2.5E13 mol/cm^2/sec @ 8.5 mW/cm^2 for 45-200 amu – 2/4/08)

➪ Negative Tone Platforms Warrant Further Investigation

Peering Around the Corner…



- **Significant RLS Gains Needed for 22 nm HP+ w/ EUVL.**
- **16/22 nm HP Aerial Image Capability Needed Soon to Provide Ample Time for Material Readiness**

➯ **While Looking to Improve Resolution of CARs, Industry Should Also Continue to Investigate non-CARs w/ Improved Sensitivity.**

[4]Solak, et al EUVL, Tahoe 2008
[5]Ekinci, et al Microelectronic Engineering 84 (2007) 700–704
[6]Naulleau, et al SPIE 69213N (2008)

Summary

- Intel-MET and Strong Vendor/ Academic Engagements Allow for World Class EUV Resist Work from First Principles to Patterning / Integration.
- New Intel Champion = Resist B + New UL + Ancillary Rinse = 30 nm HP w/ 3.9 nm LWR, 0.20 um DOF, and E_{size} = 8.7 mJ/cm^2. Continued characterization / optimization in progress.
- 32 nm HP+ Patterning is Looking Viable w/ EUVL + CAR Platforms ::
  1) *Positive-Tone : Polymer-Bound PAGs + Ancillaries are Leading the Way…*
  2) *Multi-layer Stacks : Likely Required for Integrated RLS Solution….*
- 22 nm HP+ Patterning Requires Improvement for RLS Solution ::
  1) *High Absorption Photoresists : Models + Early Data is Very Compelling, but Material Challenges are Present…*
  2) *Negative-Tone : Great Start with Best in Class Outgassing…*
  3) *Molecular Glasses : Compelling and Maturing Rapidly for 16/ 22 HP…*
- Resist Outgassing Must Remain High Priority to Meet HVM Targets.
- 16/22 nm HP Aerial Image Capability Needed Soon to Provide Ample Time for Material Readiness.
- Thin Film Effects are a Growing Concern Below 30 nm HP.

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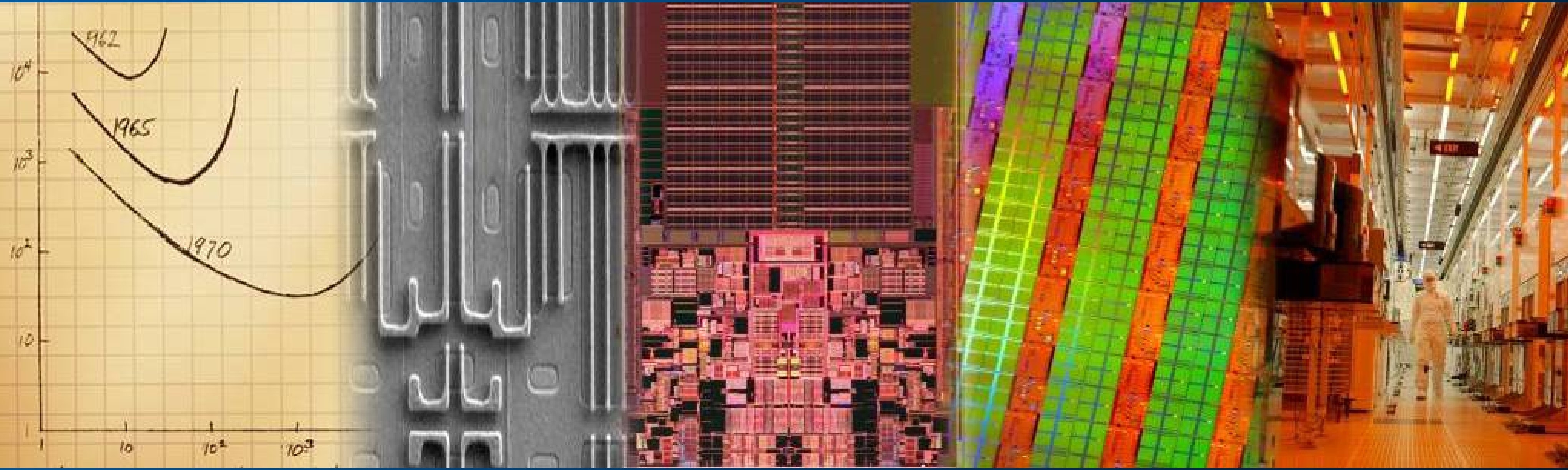
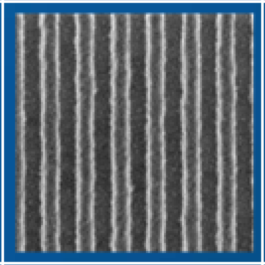
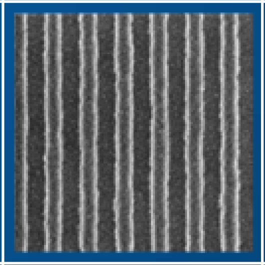
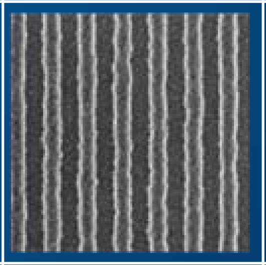
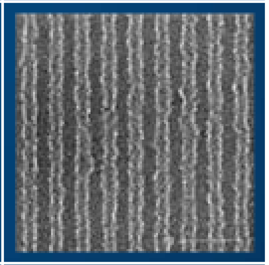


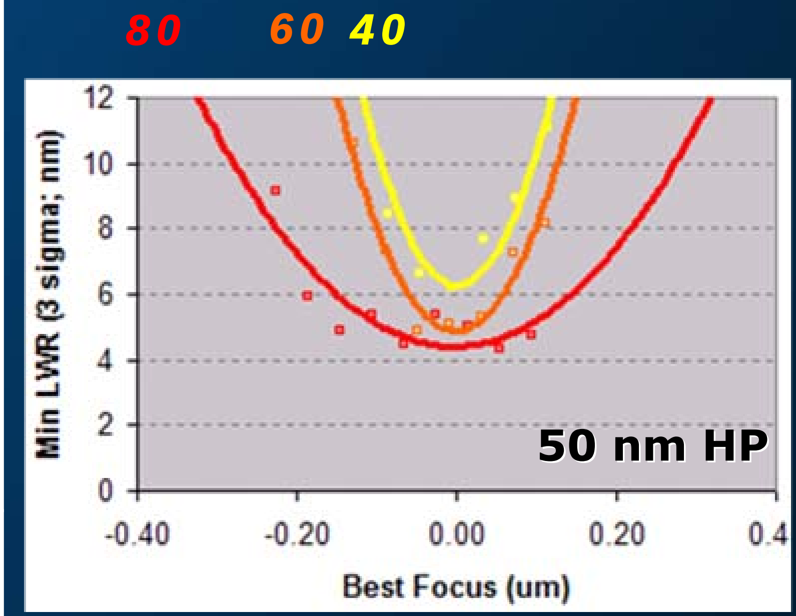
Thank You

Backup

Film Thickness Effects (Resist G)

50 nm HP

FT	80 nm	60 nm	40 nm	20 nm
				
CD (nm)	**51.0**	**48.9**	**49.1**	**53.0**
LWR (nm)	**4.5**	**4.9**	**6.2**	**10.3**
Dose (mJ/ cm^2)	**15.5**	**13.5**	**13.5**	**12.5**
NODE PC (AR=2)	**40 HP**	**30 HP**	**20 HP**	**10 HP**

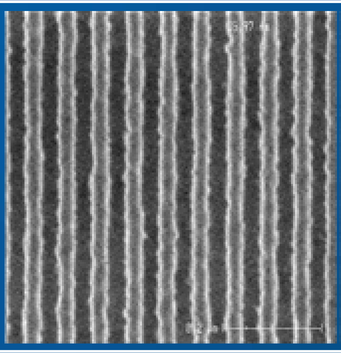
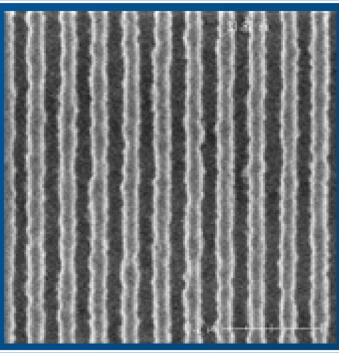
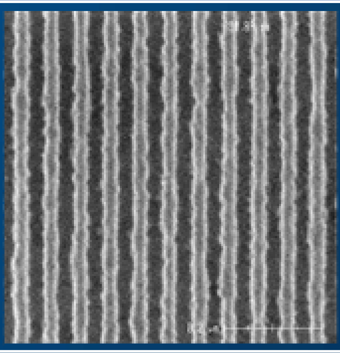
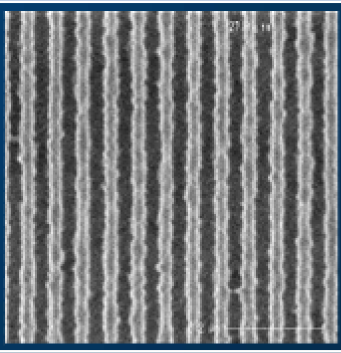
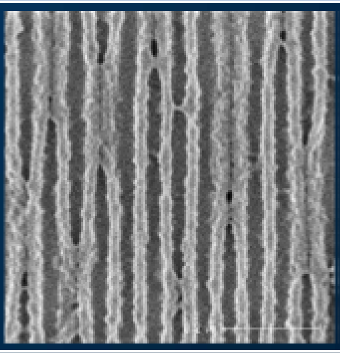


EUV Patterning Highly Dependent on Film Thickness

- Resist patterning modulates as a function of film thickness
- Acceptable levels of dark loss can become a problem in thin films
- Need to understand film homogeneity / diffusion vs. thickness

Growing Issue as Patterning Moves Below 30 nm HP

Molecular Glass Platform (Resist H)

34 nm HP	32 nm HP	30 nm HP	28 nm HP	26 nm HP
				
CD=35.9 nm	CD=33.8 nm	CD=30.9 nm	CD=27.9 nm	Pattern Collapse
LWR=5.1 nm	LWR=5.2 nm	LWR=6.2 nm	LWR=5.8 nm	
S=13.8 mJ/cm^2	S=13.8 mJ/cm^2	S=14.3 mJ/cm^2	S=14.8 mJ/cm^2	

- **MG Achieved 28 nm HP Resolution w/ Min LWR ~ 5.8 nm**

MG Resolution Finally Compelling when Compared to Polymeric Resins

- Need continued improvement in S/L
- Adhesion and thermal metrics need continued improvement

Maturation of Novel Platforms May Play Key Role in Meeting 2013$^+$ Patterning Needs