RLS optimization
K_{LUP} to understand trends

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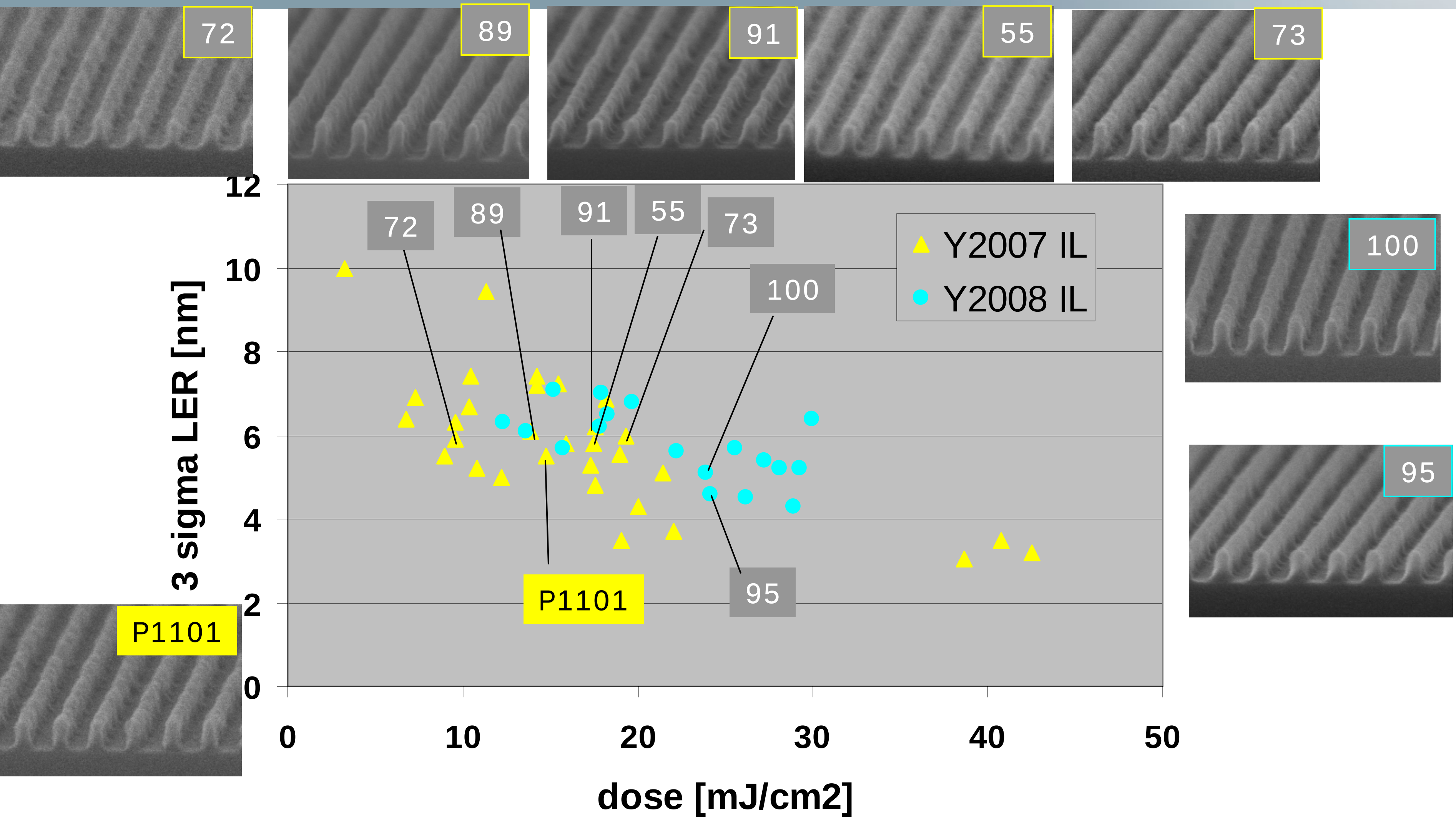
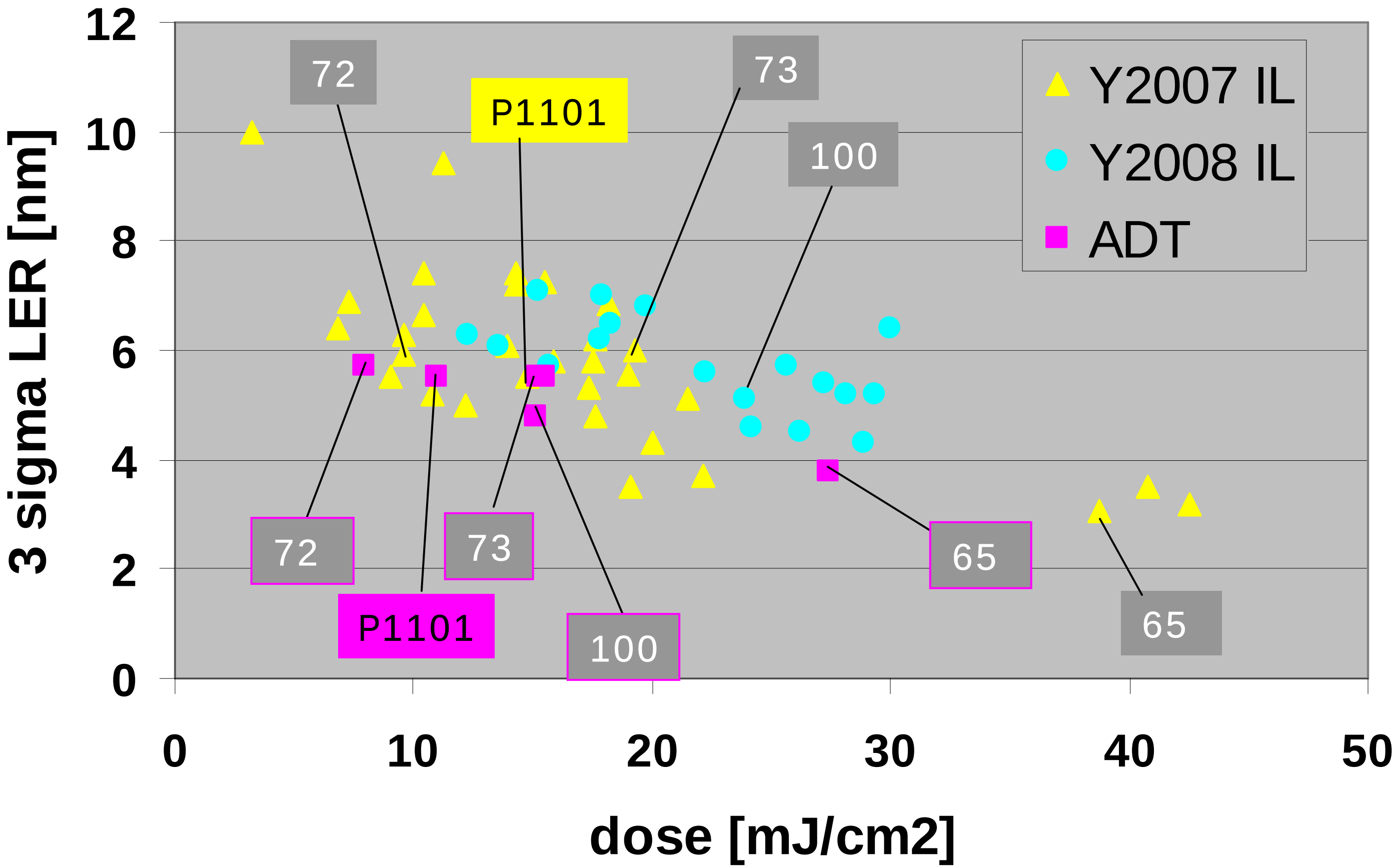
Resist screening with interference lithography at PSI
LER vs sensitivity trend



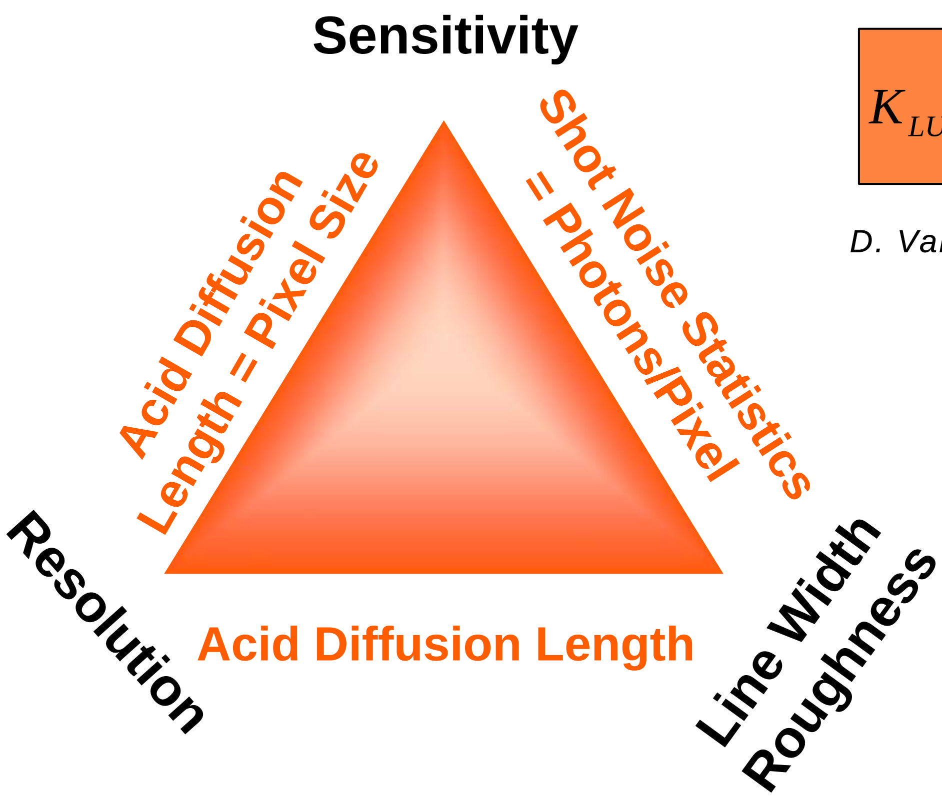
30nm L/S resolution

EUV resist screening with interference litho and on the ASML EUV ADT (NA=0.25, σ=0.5)



Similar trend LER vs sensitivity on the ADT

EUVL resist challenges - RLS



$$K_{LUP}(A,\Phi) = \sqrt{\frac{E_s}{h\nu \cdot d}} \cdot EL \cdot LWR \cdot \frac{(L_d)^{3/2}}{p}$$

D. Van Steenwinckel et al, Proc. SPIE, Vol. 6519 (2007)

Use this approach for:

- Quantitative understanding of variation of effect of resist composition parameters
- Comparison of Resists: Alternative Platforms monitor the performance of resists

Physical meaning of K_{LUP}

$$K_{LUP} = \sqrt{\frac{E_s}{h\nu \cdot d}} \cdot EL \cdot LWR \cdot \frac{(L_d)^{3/2}}{p}$$

- The K_{LUP} formula can be re-arranged to

$$LWR = K_{LUP} \cdot \frac{p}{EL} \cdot \sqrt{\frac{h\nu \cdot d}{E_s \cdot L_d^3}}$$

Amplitude

- Shot noise – deprotection statistics
- Interdependent parameters!

- Lower K_{LUP} is better
- Factor of two reduction in K_{LUP} means
  - Resist prints same features at same dose with but with half LWR

    OR

  - Resist prints same features with similar LWR, but at sizing dose divided by 4

Outline

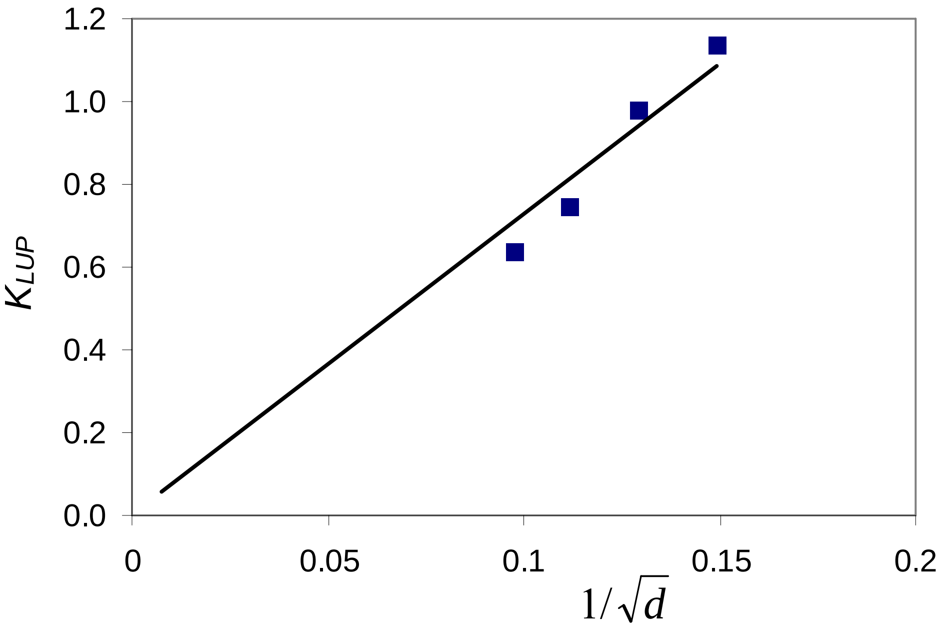
- Introduction
  - What is K_{LUP}?
- Effect of Film Thickness
- Effect of PAG Loading
- Polymer-bound PAG Resists
- Conclusion

Effect of film thickness

$$K_{LUP} \cdot \sqrt{A \cdot \Phi} = \text{Constant}$$

Therefore,

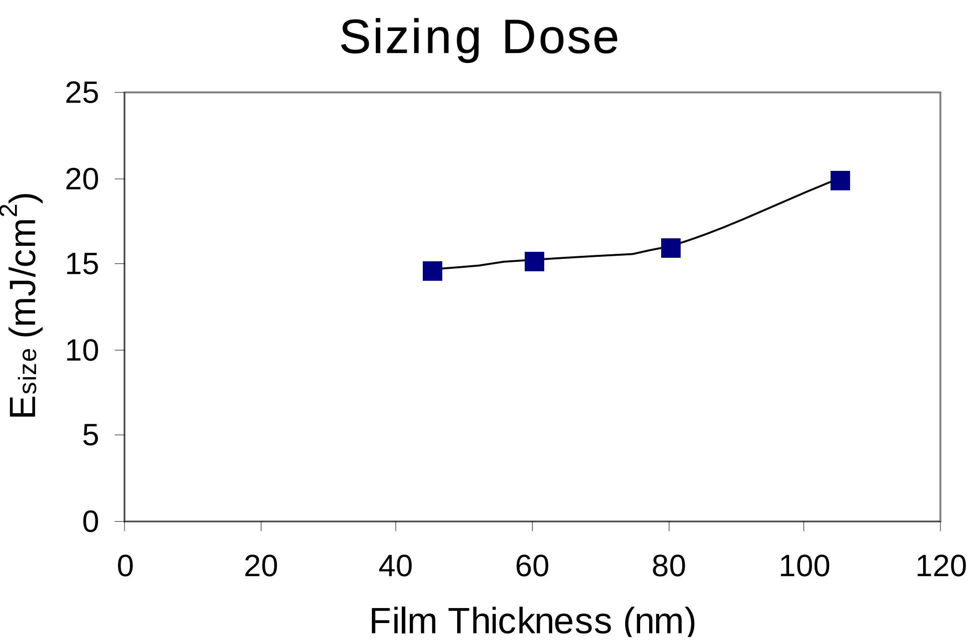
$$K_{LUP} \propto \frac{1}{\sqrt{d}}$$

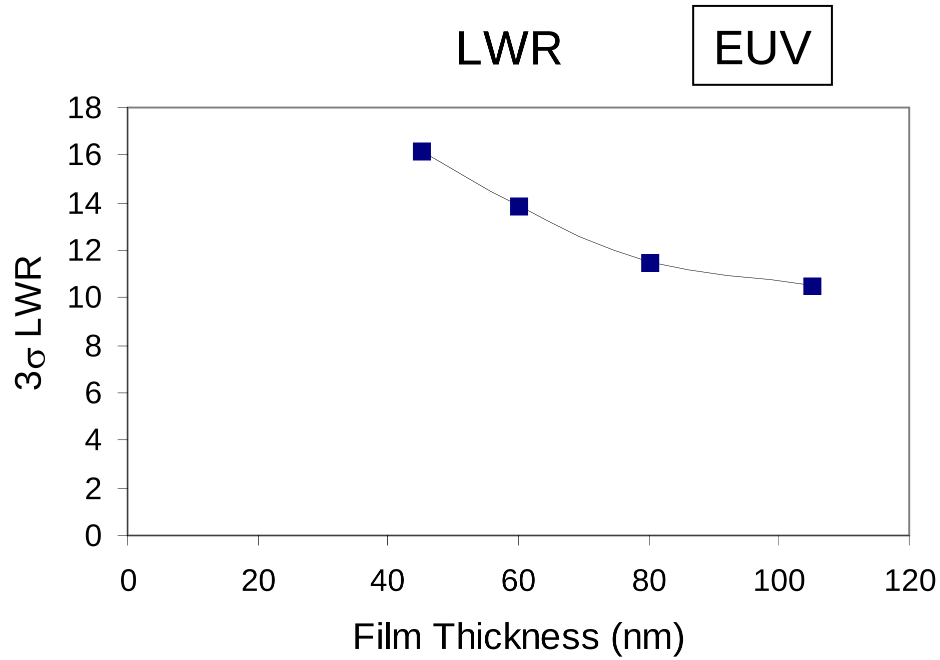


- K_{LUP} behavior versus thickness as expected
  - K_{LUP} scales with $1/\sqrt{d}$

- Important consequence :
  Any future **reduction in resist thickness** will have to be compensated by a similar **increase in effective absorbance** (effective = leading to acid creation) in order to decrease K_{LUP}

Effect of film thickness on Sizing Dose and LWR



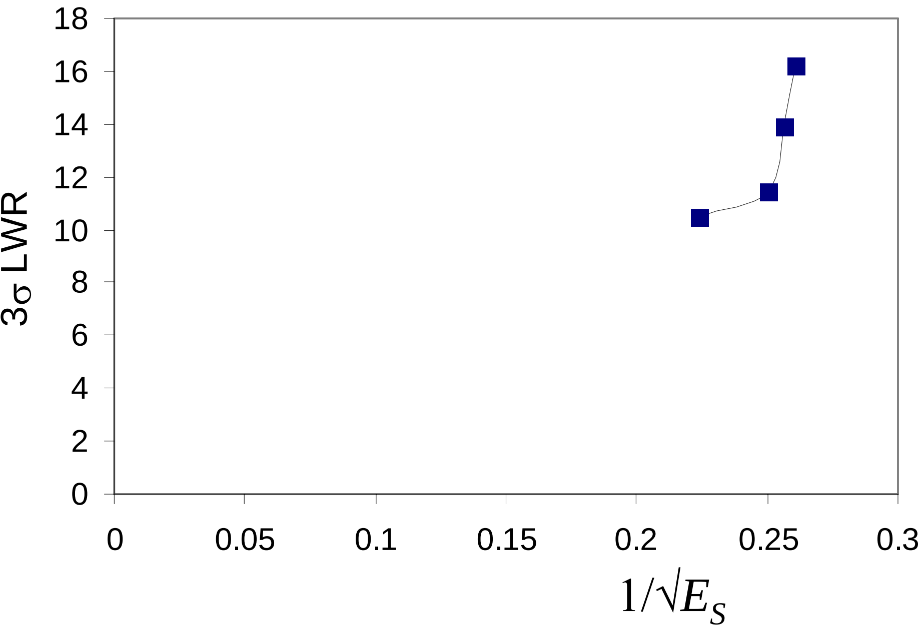


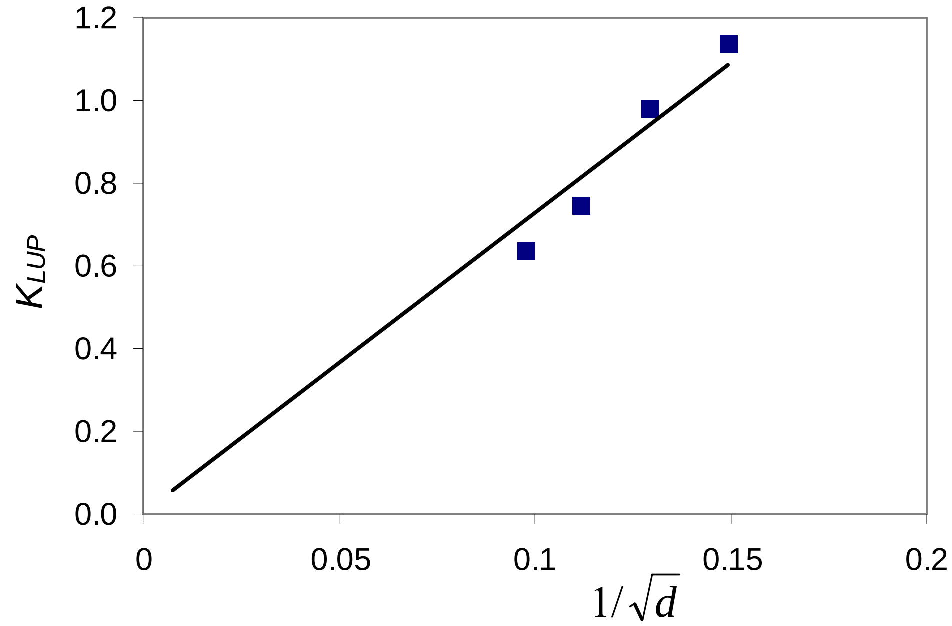
- LWR increases drastically upon reducing resist thickness
- Dose to size decreases with reducing resist thickness

Interference litho exposures

Shot noise scaling?

EUV





- Increase in LWR with decreasing film thickness is consistently found
- Increase is more drastic than expected just from shot noise scaling when based on <u>incident</u> dose
- Shot noise scaling is applicable when <u>absorbed</u> dose is considered (as done in K_{LUP})
- Need to increase absorbance for EUV resists
  - Increase F content

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PAG Loading – Motivation

- Increasing PAG loading for KrF/ArF increases Absorbance (*A*)
  - Make more efficient use of photons
  - Decrease Sizing Dose
  - Higher Acid density ⇒ Less Acid shot noise resulting in better LWR
- But too high loading leads to loss of pattern profile (in 193nm)
- Increasing PAG loading for EUV does not increase Absorbance (*A*),...
- ..., but does increase the acid quantum yield (Φ)

  Kozawa, T. et al. *J. Photopolym. Sci. Technol.* **2007**, *20*, 577
  - Make more efficient use of photons
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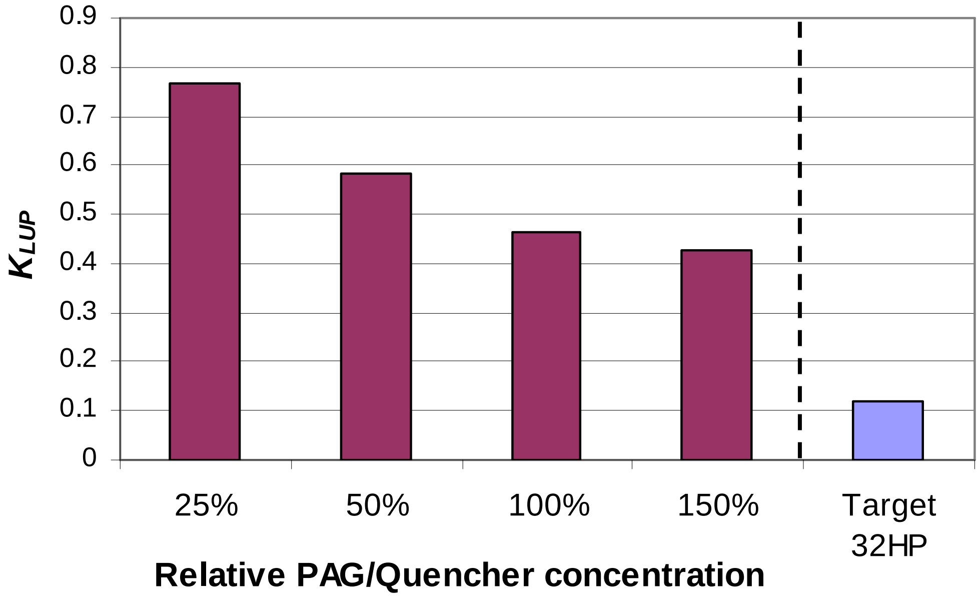
  - Higher Acid density ⇒ Less Acid shot noise resulting in better LWR

PAG loading: A way to improve K_{LUP}

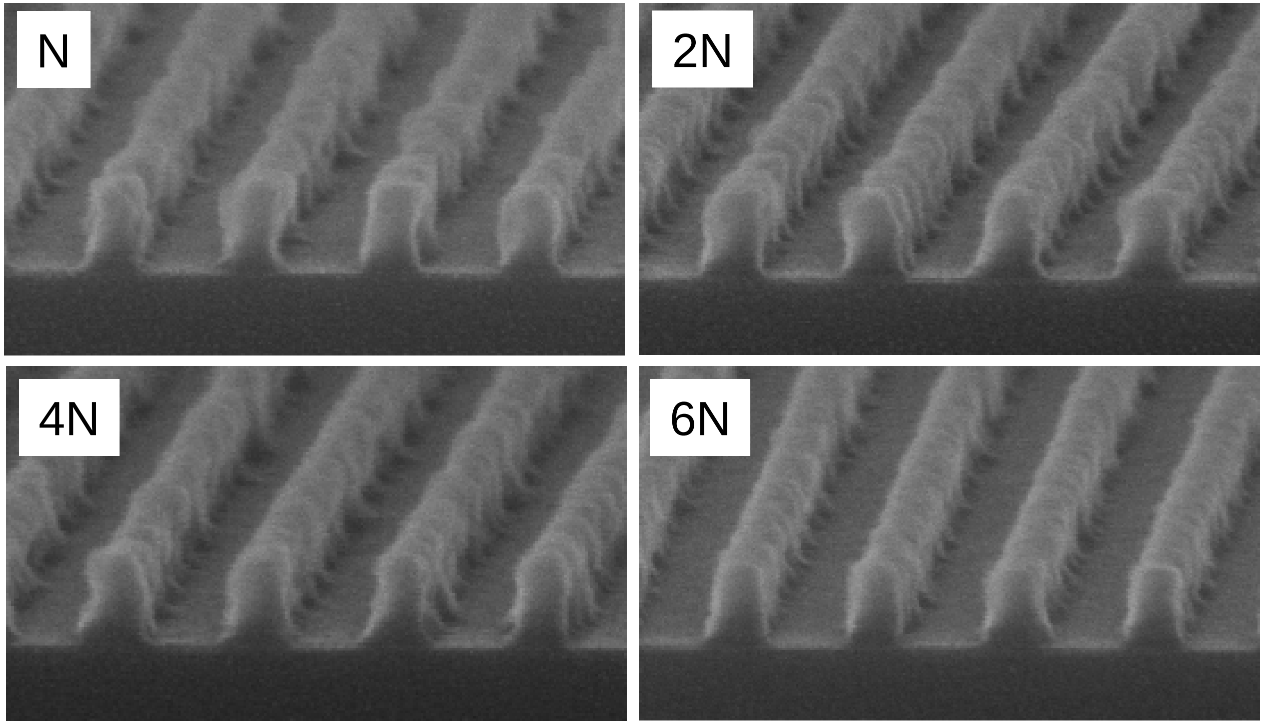


- Series of conventional model resists
- K_{LUP} decreases with increasing PAG loading due to larger acid generation efficiency

PAG loading	p (nm)	λ (nm)	E_s (mJ/cm^2)	d (nm)	EL	LWR (nm)	L_d (nm)	K_{LUP}
25%	90	13.4	13.3	80	0.187	13.6	19.1	0.79
50%	90	13.4	13.9	80	0.242	10.6	16.0	0.62
100%	90	13.4	15.8	80	0.252	8.5	14.8	0.50
150%	90	13.4	18.5	80	0.233	6.8	14.6	0.39

X-sections as function of PAG loading

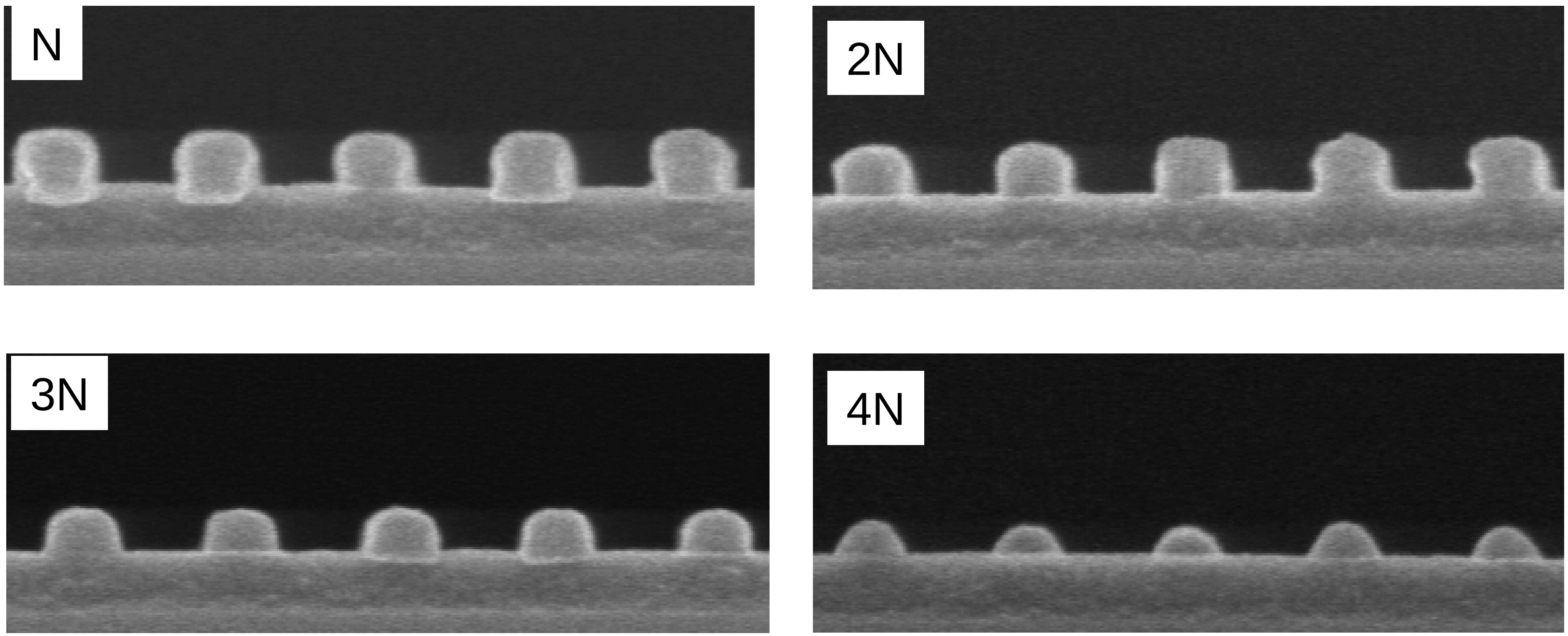
EUV



- Resist absorbance at EUV is governed by the chemical composition of the matrix, not by PAG (as in KrF and ArF)
- In EUV, increasing PAG loading reduces LWR, but does not cause sloped profiles

X-sections as function of PAG loading

193nm



- Profiles deteriorate at increasing PAG loading by top-rounding, sloped profiles and top-loss. All is caused by increased absorbance.

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Why polymer-bound PAGs?

- Suppress phase separation between PAG and polymer
  - Would allow for increase of PAG concentration
    - » Lower **Sizing Dose**
    - » Lower **LWR**
- Improve PAG uniformity
    - » Lower **LWR**
- Suppress acid diffusion
  - Better **resolution** capabilities

Assessment of Polymer-Bound PAG resists

- K_{LUP} has been determined for three EUV resists using EUV interference lithography
  - Polymer-bound PAG + blended PAG
  - Anion-bound PAG platform
  - Cation-bound PAG platform

- Apart from the PAG the three formulations are similar: same backbone and same acid labile group

- Lithographic performance of three resists are compared to EUV reference resist MET-2D

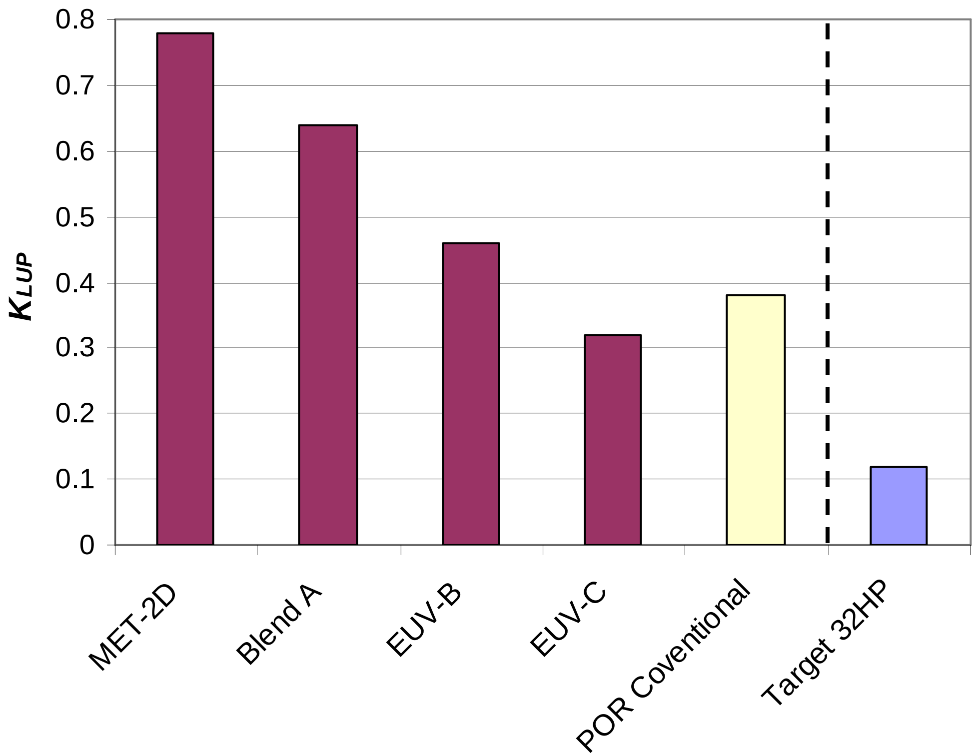
Assessment of Polymer-Bound PAG resists

	p (nm)	λ (nm)	ν (s^{-1})	E_s (mJ/cm^2)	d (nm)	EL	LWR (nm)	L_d (nm)	K_{LUP}
MET-2D	**100**	13.4	2.24E+16	22.7	90	0.12	8.1	32	**0.73**
	90	13.4	2.24E+16	24.6	90	0.11	8.7	32	**0.83**
Blend A	**100**	13.4	2.24E+16	22.8	80	0.17	6.3	26	**0.62**
	90	13.4	2.24E+16	25.0	80	0.16	6.1	26	**0.66**
EUV-B	**100**	13.4	2.24E+16	41.1	80	0.21	4.9	17	**0.43**
	90	13.4	2.24E+16	45.2	80	0.23	4.4	17	**0.49**
EUV-C	**100**	13.4	2.24E+16	37.7	80	0.23	4.6	13	**0.28**
	90	13.4	2.24E+16	42.0	80	0.24	4.8	13	**0.36**

Observations:

- *LWR* of novel resist concepts is considerably improved
- Lower L_d gives larger *EL* as a bonus
- The novel materials B and C show substantially larger sizing doses
- Yet, novel materials exhibit significantly lower K_{LUP} values

Assessment of Polymer-Bound PAG resists



- Polymer-bound PAG resists show very promising results
  - EUV-C exhibits lowest K_{LUP} so far
  - Blend-A and EUV-B show intermediate results

Conclusions

- Scaling of resist film thickness <80nm can only be maintained if resist absorbance can be sufficiently increased
  - For EUV this may become problematic
- For EUV resists PAG loading should be maximized (while avoiding phase separation)
  - No negative impact observed on profile, exposure latitude or resolution
  - Larger acid concentration improves LWR
- Polymer-bound PAG resists offer an attractive path for achieving high PAG loading
  - These materials show best K_{LUP} performance thus far
- K_{LUP} is a useful metric for understanding resist performance and comparing different formulations
- RLS improvement by
  - Increasing polymer absorbance
  - Increasing Quantum yield
  - Post processing to reduce LWR

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