EUV Resist: Sensitivity, Resolution, and LWR Targets

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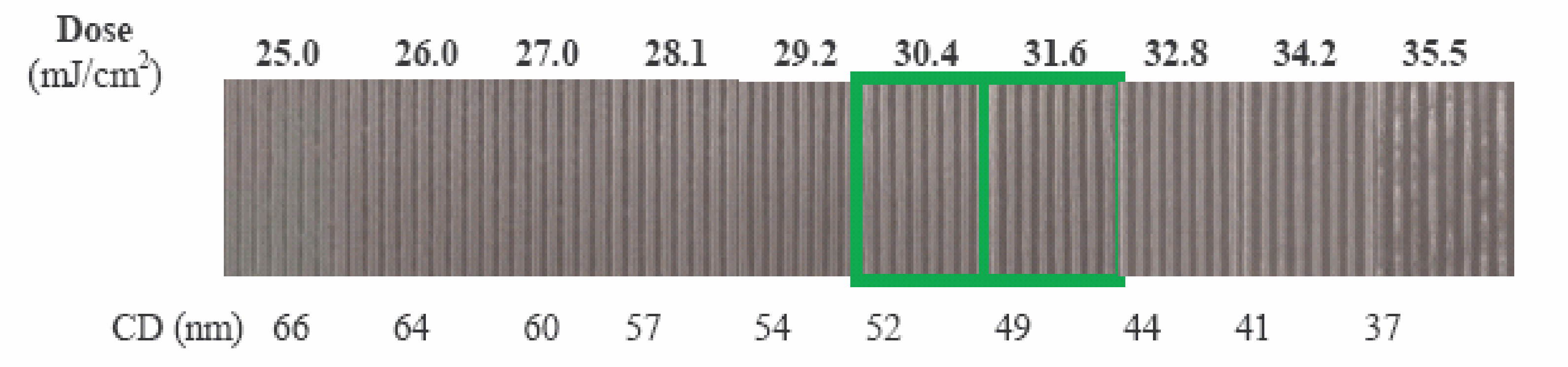
Outline

- Background
- Experimental data
- Current resist platforms
- Next generation EUV resists
- Conclusions

Do resist sensitivity targets need to be changed?

- Many of the reports on high resolution EUV resists that have recently been published have been for low sensitivity resists. This has resulted in some discussion, as to whether the EUV resist sensitivity targets should be modified.



Koehler et. al, SPIE, 2005

- Changing the sensitivity targets for EUV resists may impact source power requirements. Doubling the sensitivity target may double source power requirements, unless tool suppliers are able to find other ways to increase the power that makes it to the wafer.

Resist targets

- Resolution : 32 nm node and beyond
- DOF: ≥ 0.2um
- Line Width Roughness (LWR) (3σ) : < 1.5 nm
- Photo Sensitivity: 2-5 mJ/cm^2
- Side wall angle: 90º ± 2º
- Outgassing: 10^{10} - 10^{11} m/cm^2 at Esize

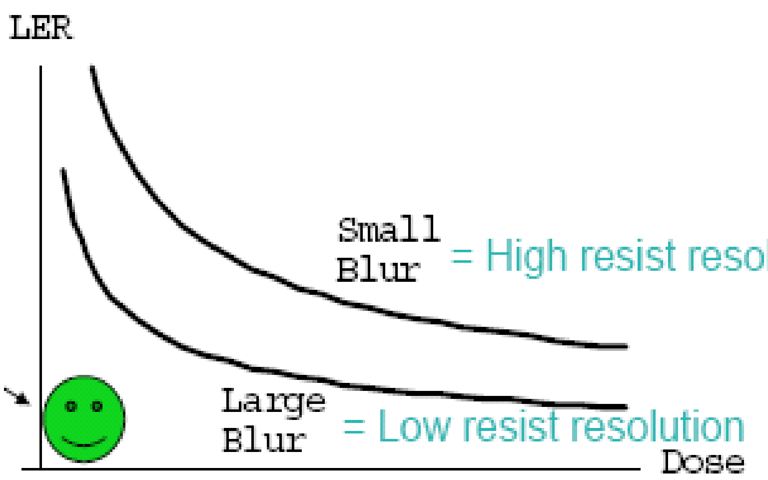
(Note: Outgassing spec is Intel's initial recommendation. Final outgassing spec will be set by tool suppliers Sematech Resist TWG.)

Challenge: Simultaneously meeting sensitivity, LWR, and resolution targets

- **It has been observed that there are trade-offs between resolution, sensitivity, and LWR.**

- **Gallatin completed an analytical model of acid distribution, and concluded that it was only possible to get two of the three targets.**

"LER, Dose, Resist Resolution… Pick any two."



Gallatin, SPIE, 2005

- **Gallatin assumes that sensitivity, resolution, and LWR are governed entirely by acid diffusion, and is therefore limited in its predictive ability.**

Possible Sources of LWR

- Although increasing the number of photons can modulate LWR to some extent, it will not reduce it to zero even at infinite doses indicating that there are other sources of LWR.

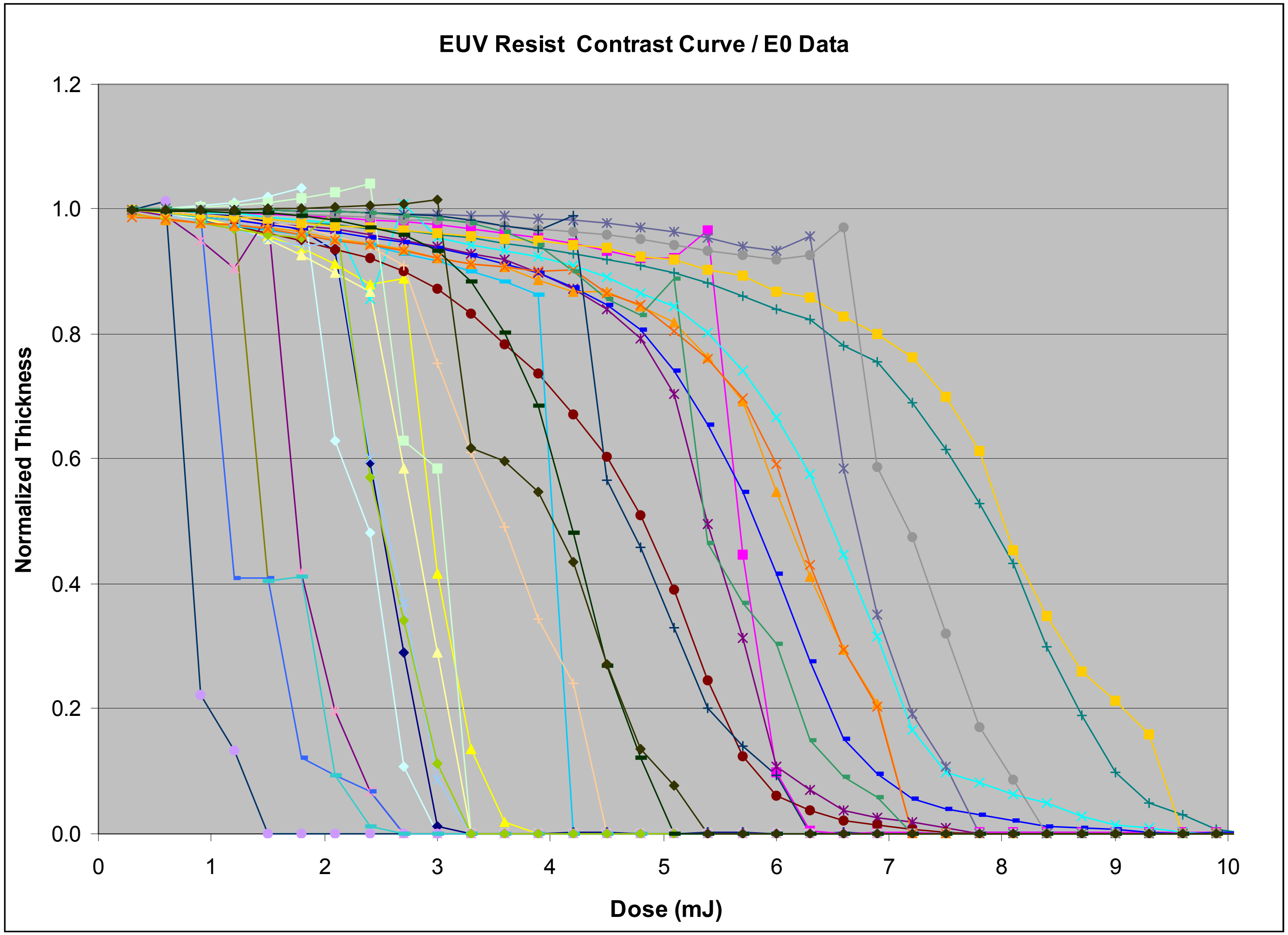
1. Inhomogeneous mixing of resist components (PAG clustering, polymer blockiness, phase separation between protected and unprotected resist, etc)

2. Statistics of acid diffusion (Non-uniform acid diffusion, shot noise, etc)

3. Inhomogeneous Development (Non-uniform dissolution of partially deprotected polymers)

4. Molecular size (Polymer radius)

Current Status (Sensitivity)



Typical Dose-to-Print:

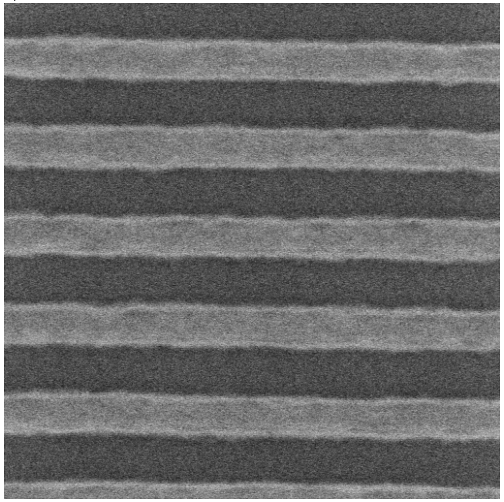
Nested Lines
2-3 x E0

Isolated Lines
1.5-2.5 x E0

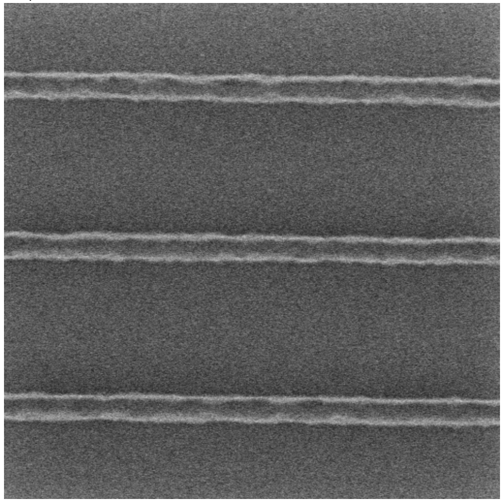
Holes
3-5 x E0

Candidate Resist Example

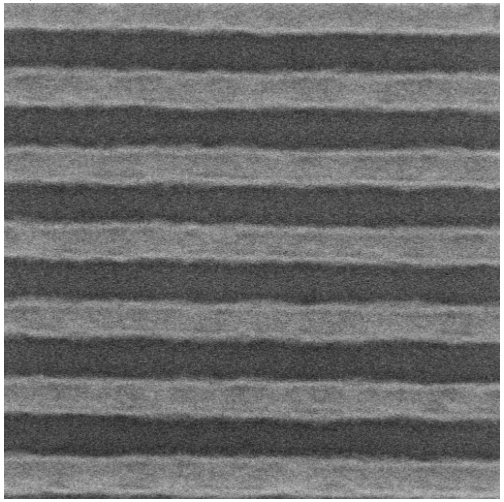
Target: 60nm Line, 120nm Pitch
CD: 59.6nm
LWR: 5.6nm
Dose: 11.5mJ



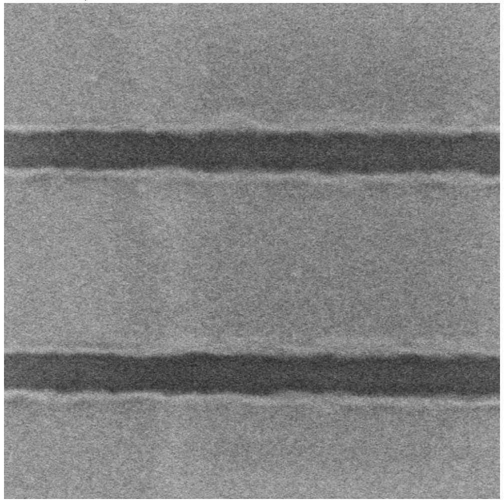
Target: 60nm Line, 360nm Pitch
CD: 58.1nm
LWR: 7.2nm
Dose: 9.5mJ



Target: 52nm Line, 104nm Pitch
CD: 46.4nm
LWR: 6.8nm
Dose: 11.5mJ

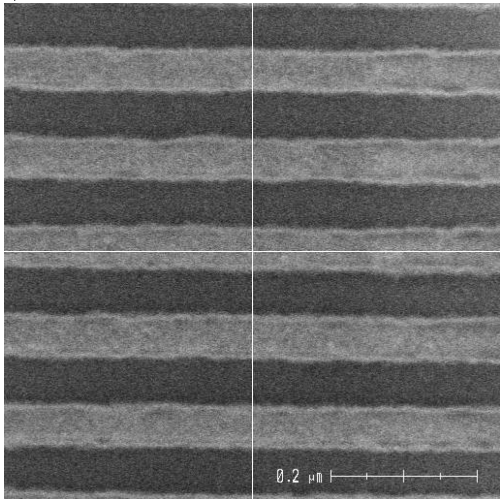


Target: 60nm Trench, 360nm Pitch
CD: 73.0nm
TWR: 6.9nm
Dose: 9.5mJ

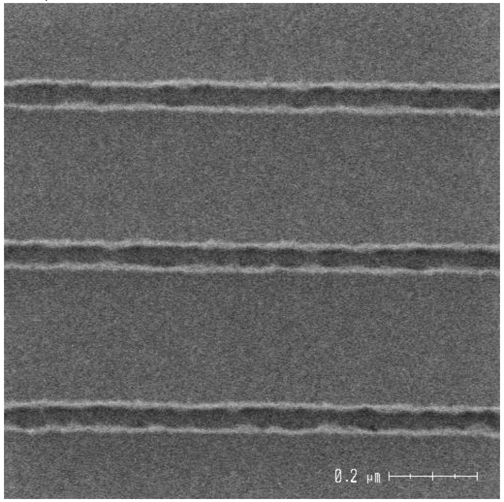


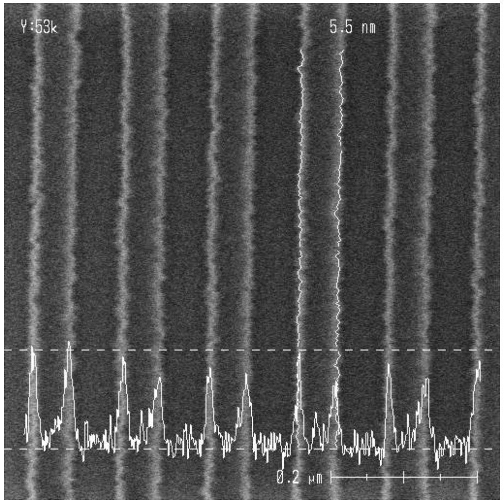
Candidate Resist Example

Target: 60nm Line, 120nm Pitch
CD: 57.7nm
LWR: 5.5nm
Dose: 10mJ



Target: 60nm Line, 360nm Pitch
CD: 66.5nm
LWR: 6.5nm
Dose: 8.75mJ

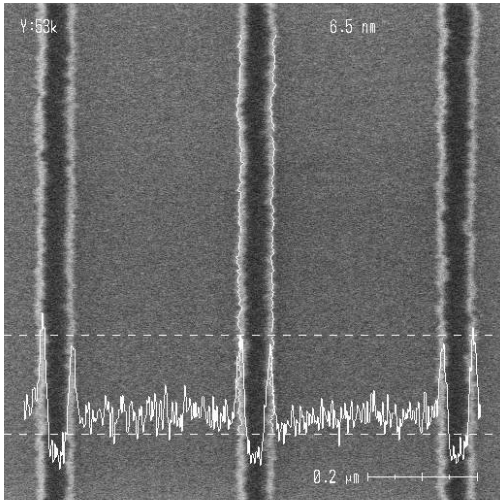




Rectangular SEM Scan

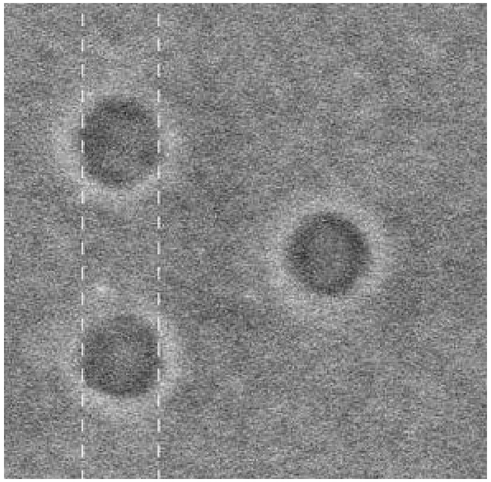
Xmag 200K
Ymag 52.7K
(2µm)

Used for LWR measurement

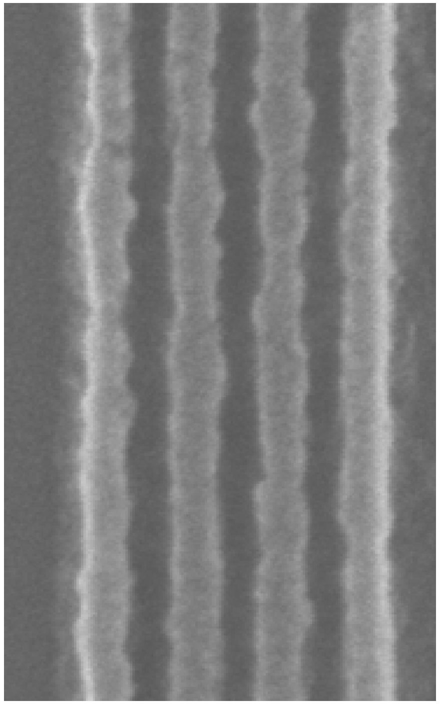


Patterning Examples

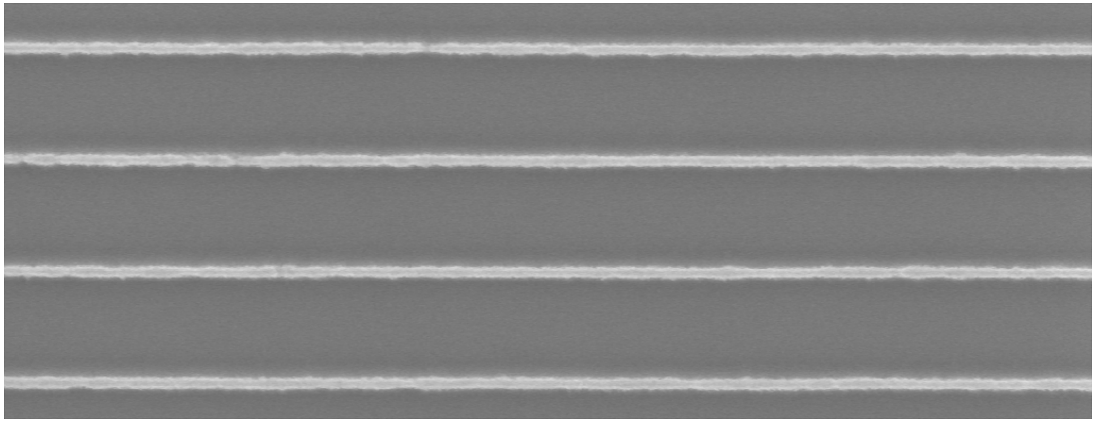
41nm CON



35nm 1:1 L/S Resist

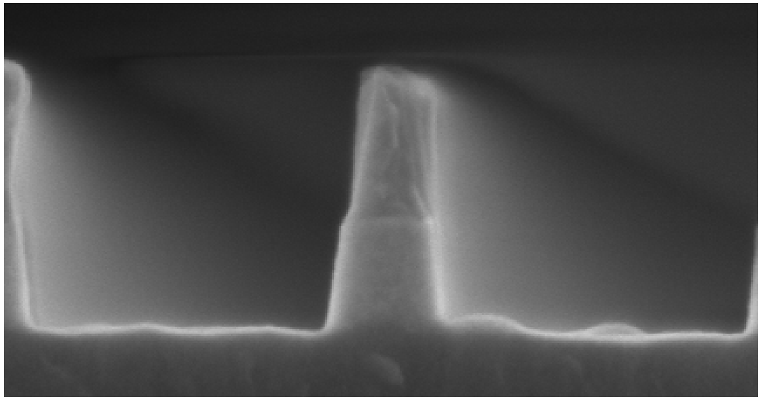


27nm Isolated Resist

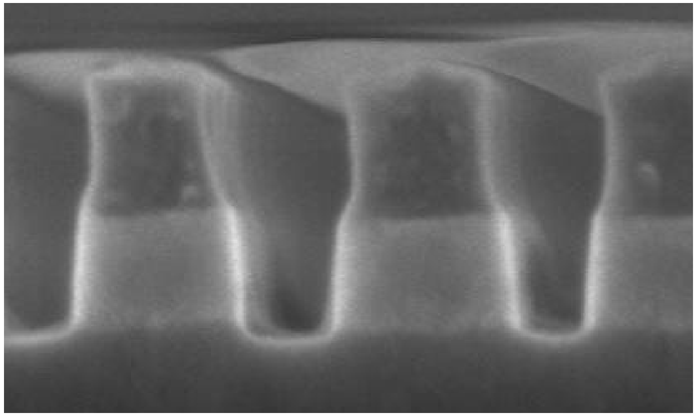


Preliminary Etch Results

40nm Isolated Etched HM

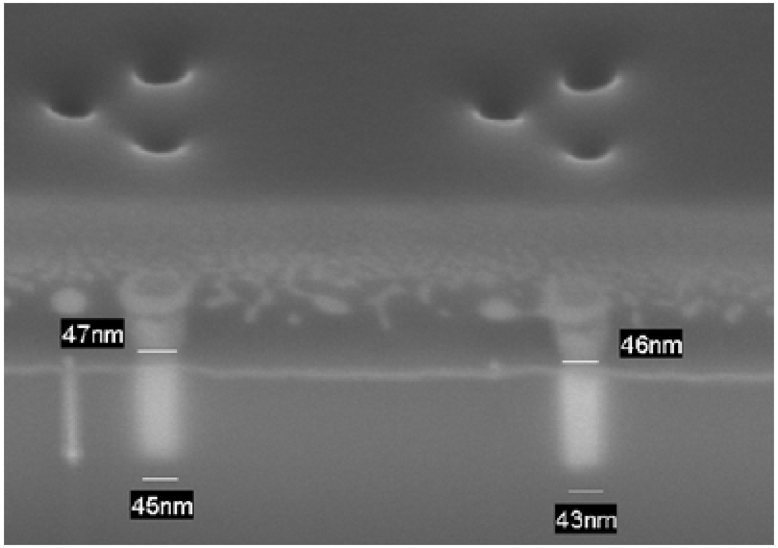


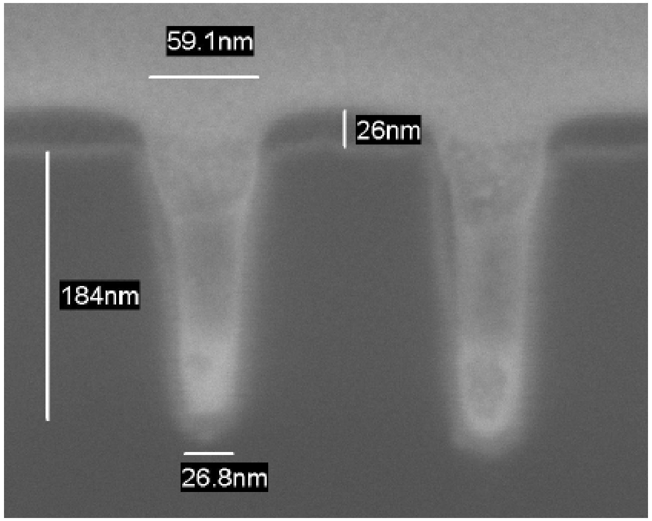
60nm 1:1 Etched HM



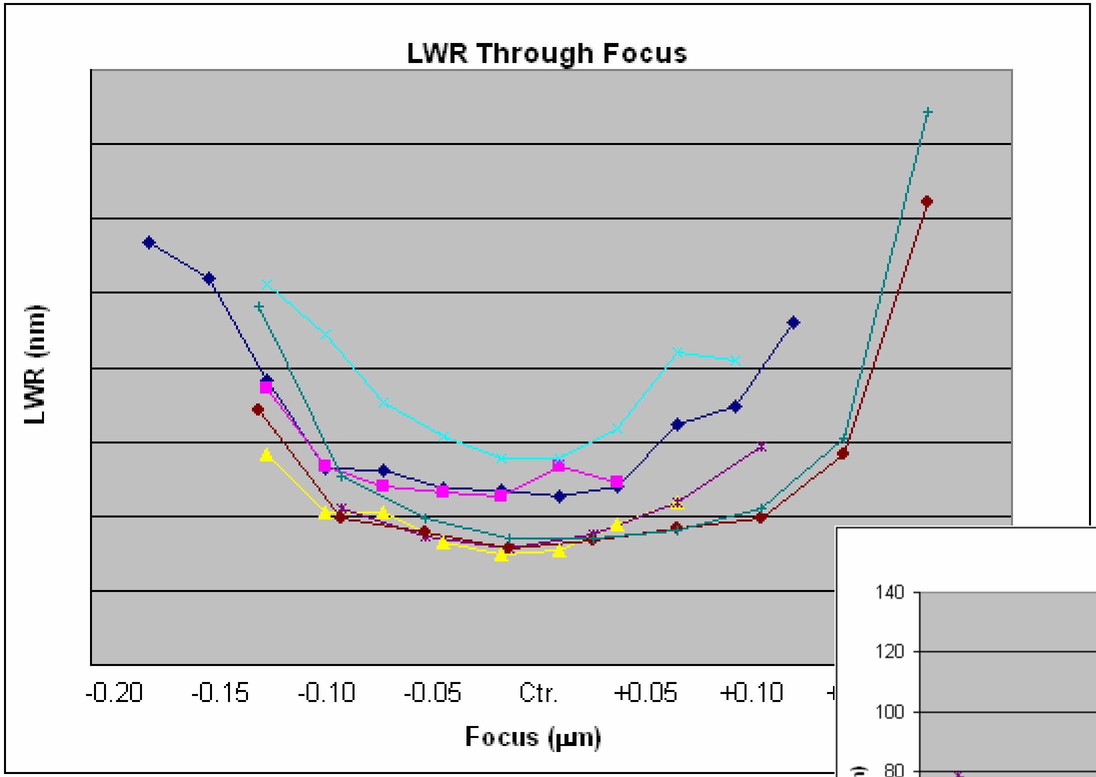
Current EUV resist platforms show good etch resistance.
Use of thin resists (low AR) possible.

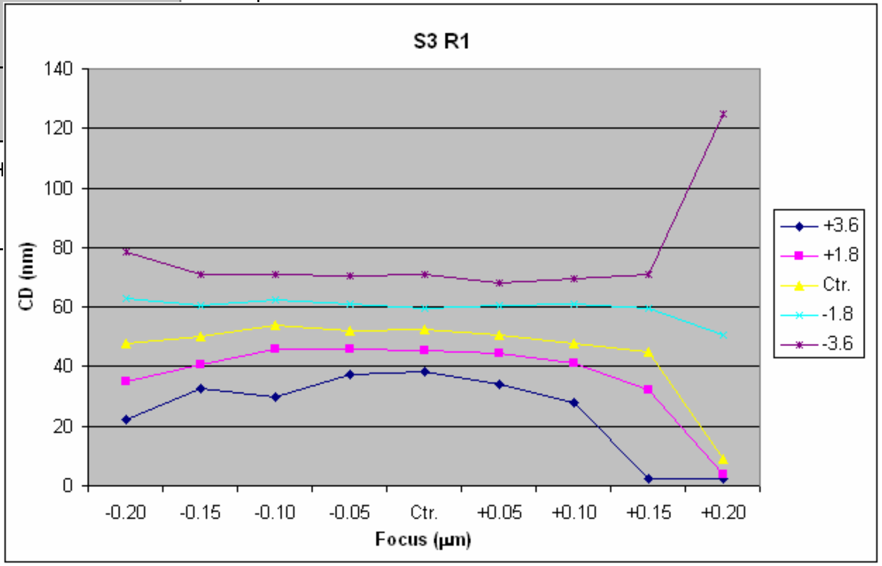
Etched Oxide Holes





LWR DOF Vs. CD DOF



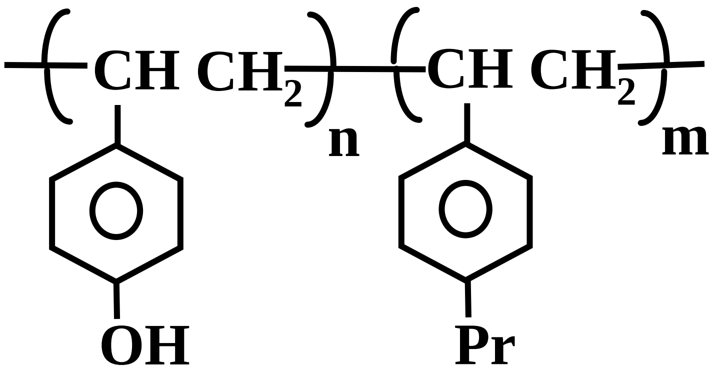


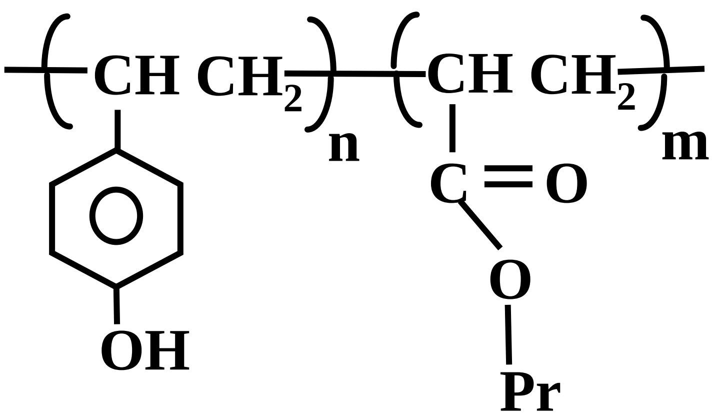
LWR strongly dependant on focus.

LWR DOF process window may be smaller than CD DOF process window.

Literature – Current EUV resist platforms

Early versions of EUV resists are: 1) chemically amplified, and 2) based on polyhydroxystyrene (PHS) polymers[1,2].



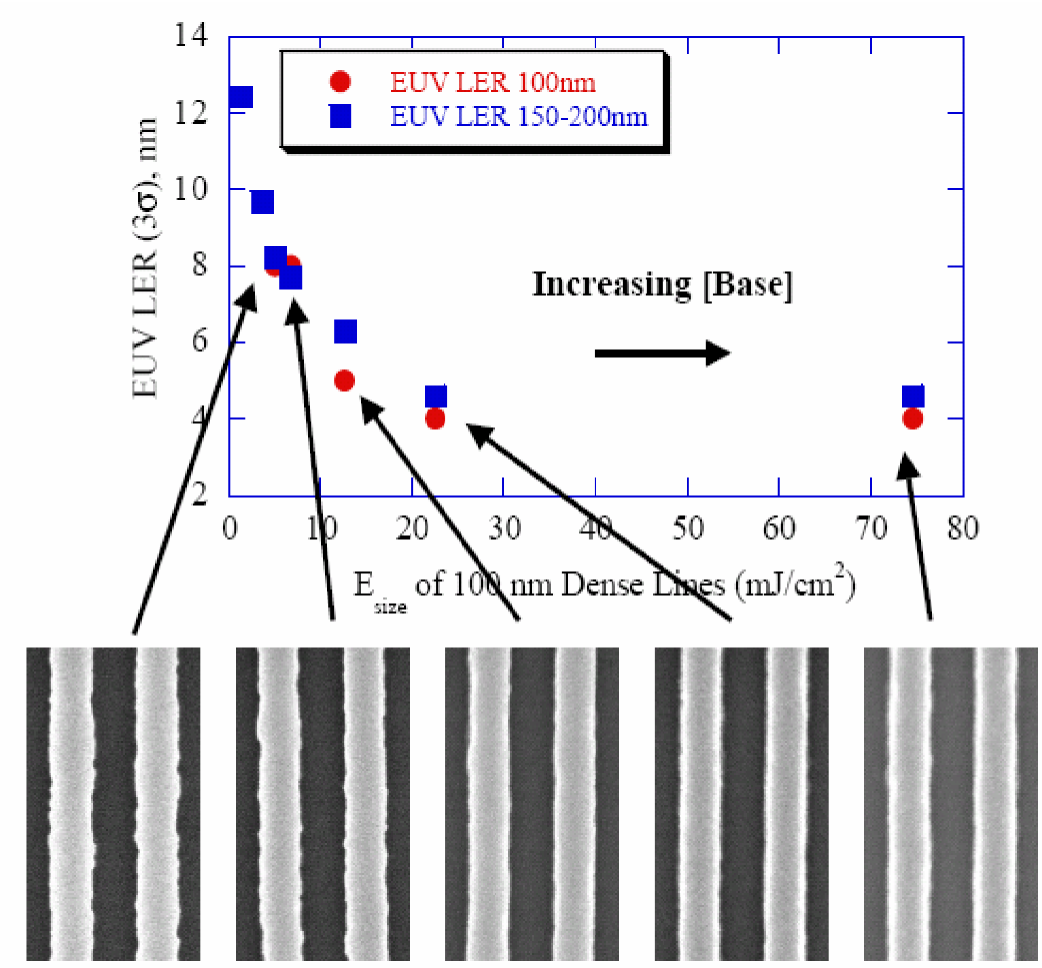


- **Early versions of EUV resists show similarities to DUV resists.**
- **However to meet stringent patterning requirements for the 32 nm node, significant improvement will be required.**

1. Cao et. al., SPIE, 2004

2. Brainard et. al. SPIE, 2004

Literature - Impact of base loading



Brainard et. al., SPIE, 2003

- Base loading can improve LWR to some extent , but at the expense of sensitivity.
- Best value of line edge roughness (LER) is ~4 nm (corresponding to a LWR value of ~6 nm) which is still very far from Intel targets.
- Changing base loading is not sufficient to meet resist targets.

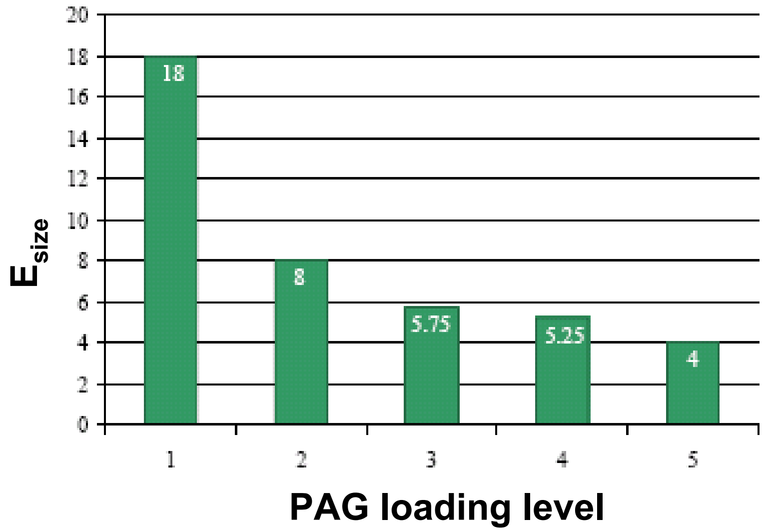
Other formulation parameters require optimization

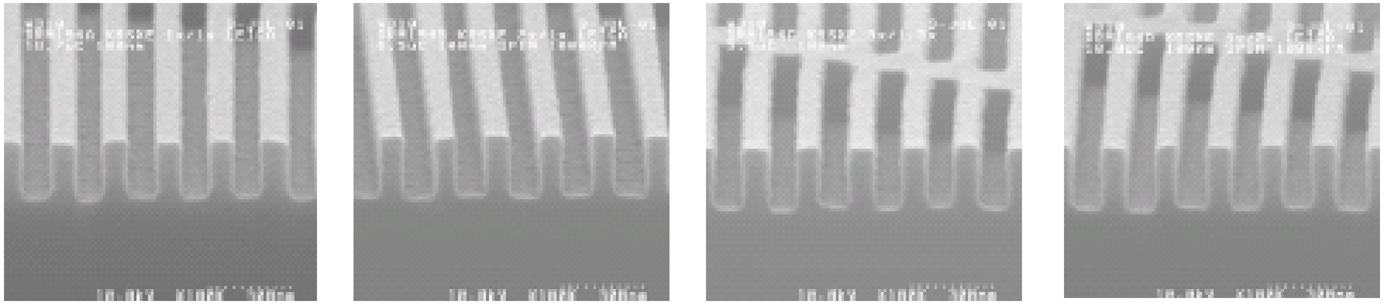
- Development of new resist platforms requires optimization of many resist components, not just optimization of base loading. A few of the parameters that need to be optimized are listed below:

  - Protection level
  - Activation energy of protecting group
  - Polymer blockiness
  - Polymer polydispersity
  - Polymer molecular weight
  - Acid efficiency
  - PAG loading levels
  - Surfactant and other additives
  - Develop and processing conditions

PAG loading level

- PAG loading levels have a significant impact on photoresist sensitivity.

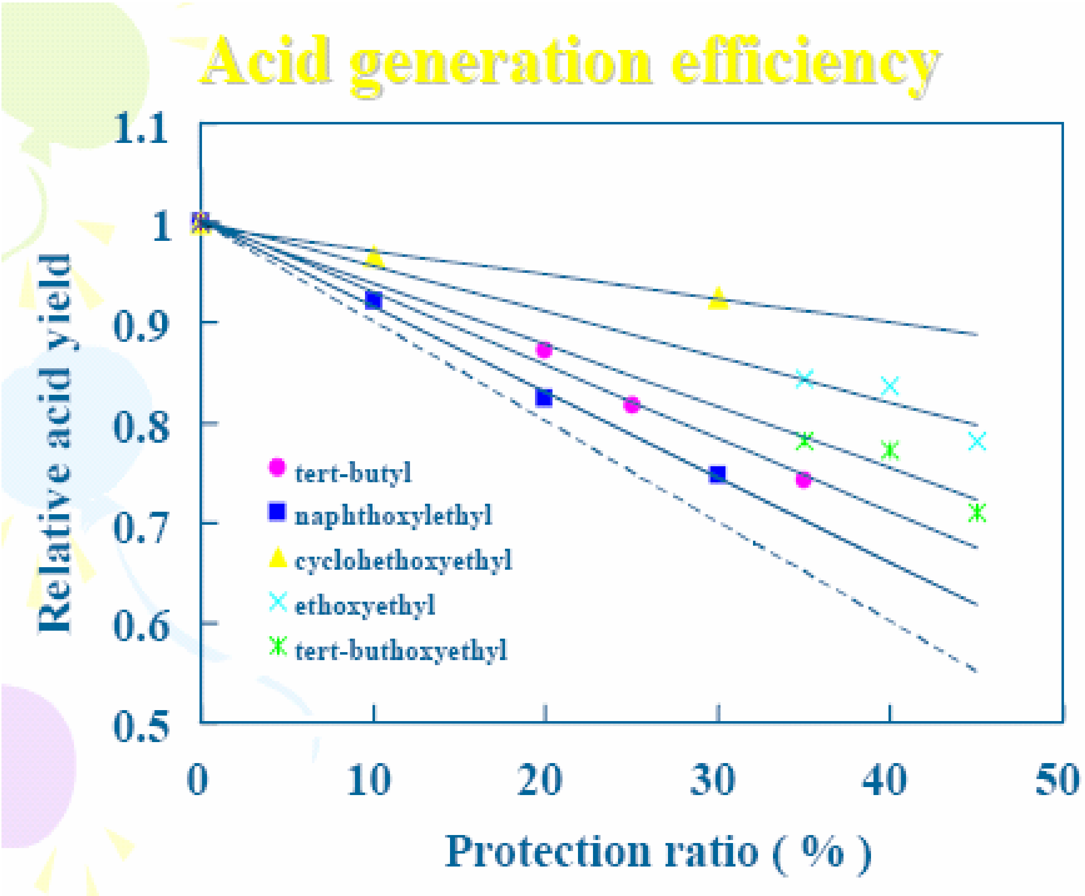




PAG Level:	1	2	3	4
PAG-to Base Ratio:	1	2	2	2
Dose [$\mu C/cm^2$]:	19	8.5	9.5	10

Medeiros et. al., BACUS, 2002

Optimization of acid efficiency



Tagawa et. al., EUVL Symposium, 2004

- **Tagawa et.al. showed molecular modeling results indicating that acid efficiency is a function of polymer structure, not just PAG.**
- **Further resist optimization will be required to maximize acid efficiency through both PAG and polymer design.**

Formulation Experiment Example

Experiment:

Sample C
High PAG Loading

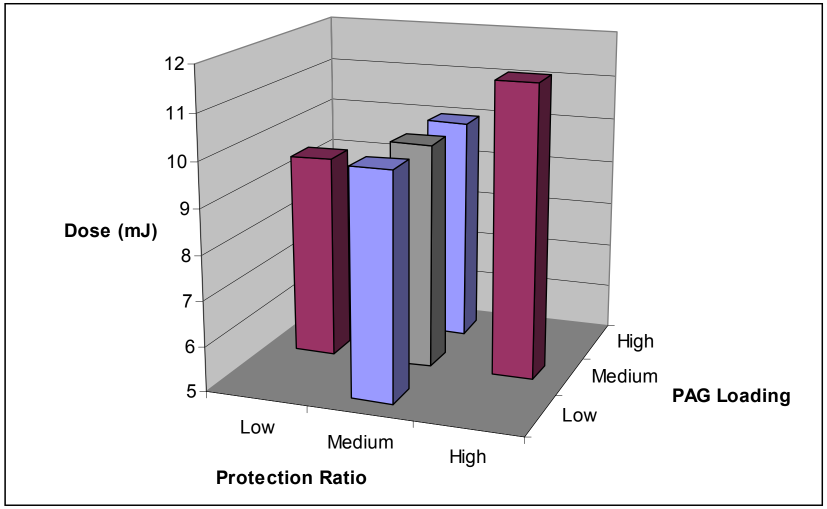
Sample D
Low Protecting Ratio

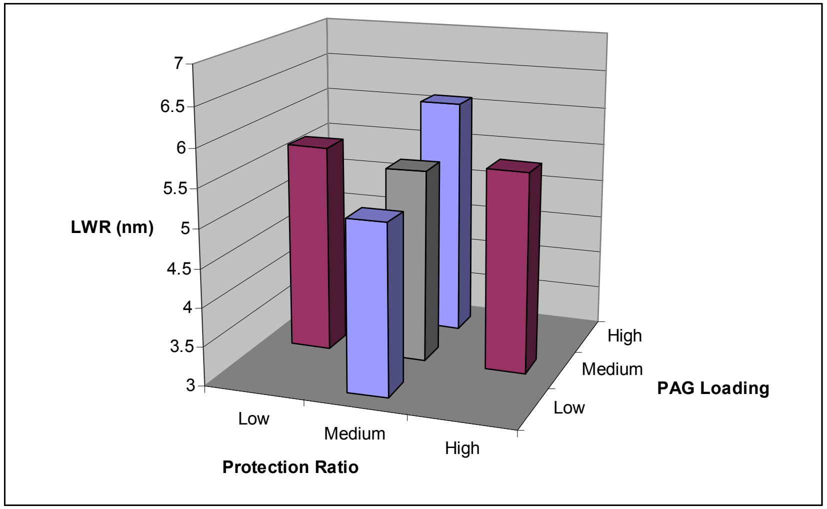
Sample A

Sample E
High Protecting Ratio

Sample B
Low PAG Loading

Results:





Conclusions:

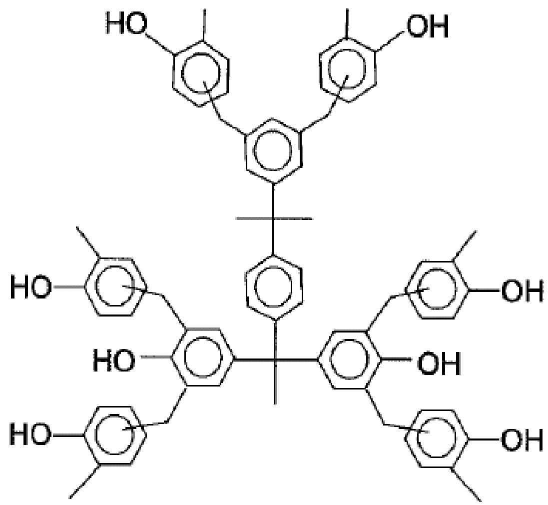
- As PAG loading increases, E0 decreases slightly, but dose to print stays roughly the same (possibly photon rather than PAG limited) and LWR increases slightly. (possibly due to increased PAG clustering)
- As protecting ratio increases, dose to print increases and LWR remains roughly constant. (Points to PAG controlling LWR more so then protecting ratio.)

Novel solutions may be necessary

- Optimization of current platforms may not be sufficient to meet resolution, LWR, and sensitivity targets and may require the development of novel resist platforms. A few examples are:

  - Small molecule / molecular glass resists
  - PAG attached to the polymer backbone
  - Chain scission resists
  - Photodegradable bases

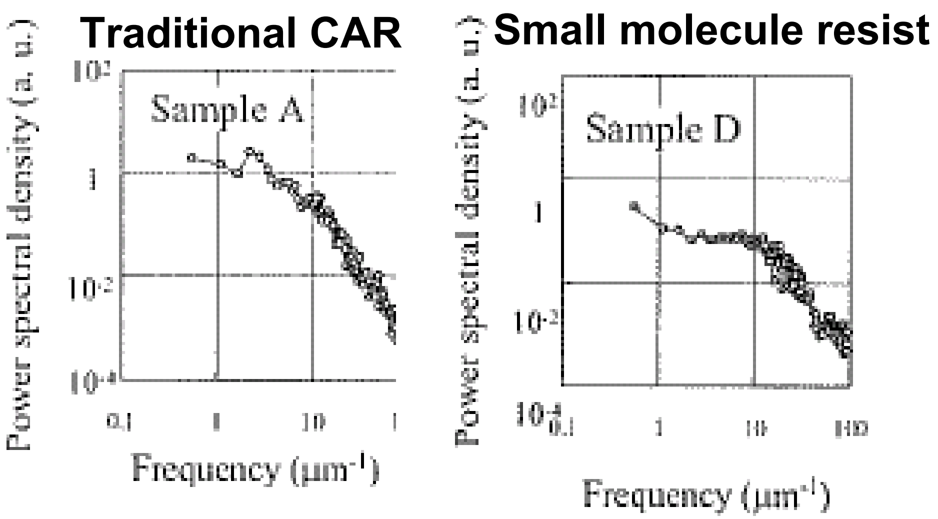
Small Molecule / Molecular glass resists



Sample structure of a small molecule resist

- **Yamaguchi et. al. demonstrated a decrease in LWR (especially low frequency LWR) for small molecule resists.**

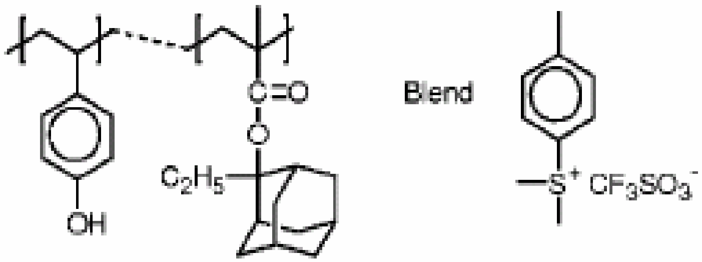
<u>Frequency of LWR</u>



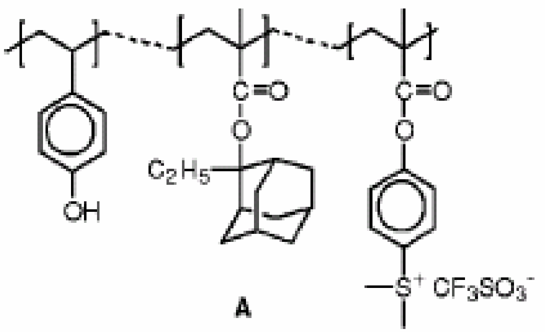
Yamaguchi et. al., EIPBN, 2005

PAG attached to polymer backbone

PAG / polymer blend



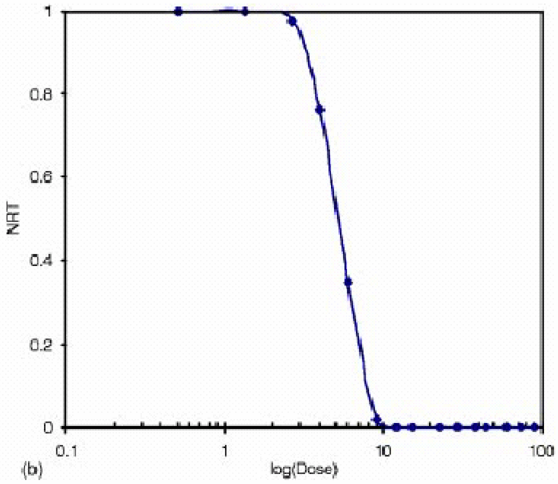
PAG bound to polymer

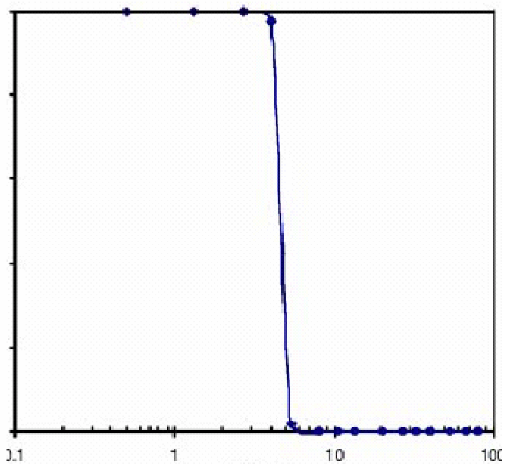


- **Gonsalves et. al. found that resists with PAG bound to the polymer had better sensitivity and resolution, than traditional PAGs. Binding PAGs to polymer may also improve LWR if PAG clustering is contributing to LWR.**

PAG / polymer blend: Sensitivity = 9.3 mJ/cm^2

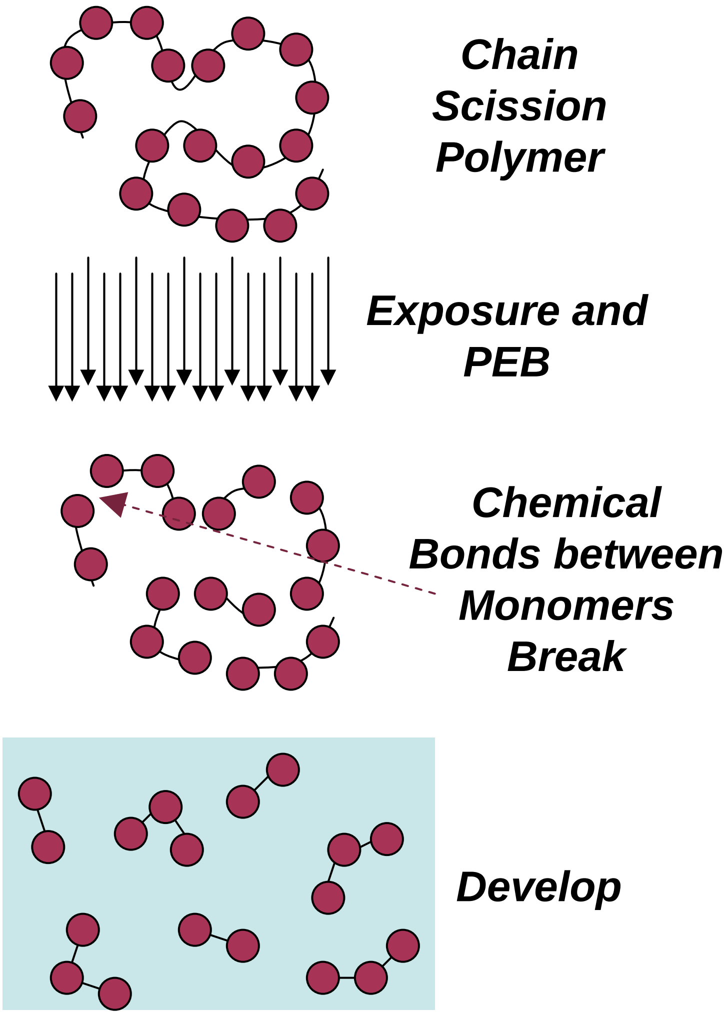
PAG bound to polymer: Sensitivity = 5.5mJ/cm^2





Gonsalves et. al., J. Microlith, Microfab, Microsyst. Vol 4(2), 2005

Chain scission resists



- Eschbaumer et. al. demonstrated that chain scission resists showed a significant reduction in LWR over traditional e-beam resists.

CD (nm)	3σ LER for E-beam Resist	3σ LER for Chain-scission Resist
350	13	6
250	13	5
200	12	4
175	10	4
150	11	4
125	10	-

Eschbaumer et. al., J. Photopoly Sci Tech Vol 16, 2003

Conclusions

- Reducing the resist sensitivity will improve LWR only to a small degree, indicating that other factors contribute significantly to LWR.

- Significant work is needed to reduce LWR of next generation resists and will require new strategies. Reducing the sensitivity targets for these resists is not sufficient to meet LWR and resolution targets.

- Much optimization of EUV resists is still needed, and it is early to predict final performance capability of EUV resists. However initial results show promising results for high sensitivity resists.

Acknowledgements

- Many thanks to the resist suppliers to their hard work and effort in developing next generation resists.
- Lawrence Berkeley National Lab, Sematech, and University of Wisconsin for access to resist screening facilities.