

EUV Resist Limits – new screening results

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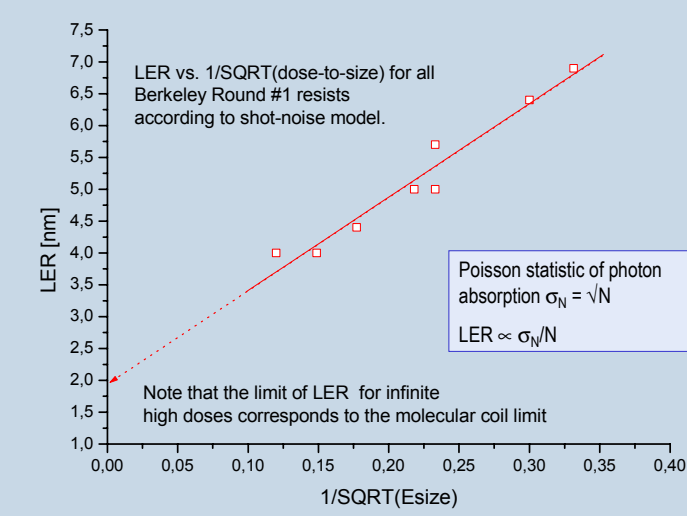
Abstract

Line Edge Roughness (LER) is recognized as one of lithography's difficult challenges for sub-50nm nodes and has thus been an important criterion for the performance of EUV resists over the last years. In the last twelve months a number of resist screening rounds at the Berkeley ALS/MET have been performed with two major results:

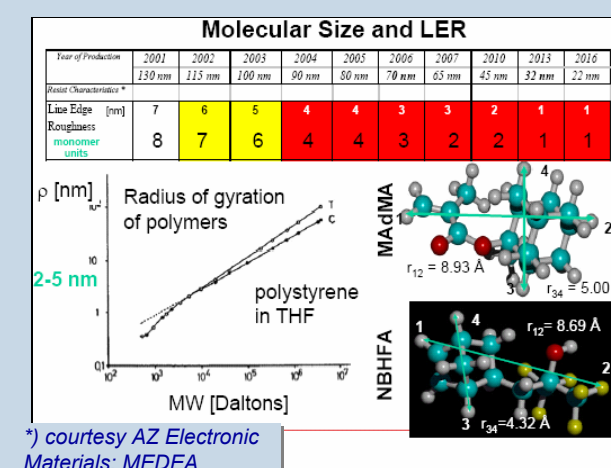
- 1) the LER/sensitivity behaviour is still dominated by shot noise – i.e. due to Poisson statistics sensitivity and line edge deviations are inversely proportional – and this correlation is valid for a variety of resists and resist suppliers.
- 2) the low-sensitivity limit of LER has slowly improved over the last two years for all resists and suppliers and is now approaching 2 nm, which is a molecular limit in terms of polymer coil size. This paper gives details about the recent resist screening results and discusses the different views of CPU manufacturers and memory manufacturers on molecular LER limits.

Shot Noise Behavior & LER molecular limits

LER (3σ) limit for high doses is 2 nm – which is approx. the 3σ molecular coil size of today's photoresists



Contemporary resists have 2-3 nm polymer diameters (coil sizes) and up to 5nm intermolecular distances

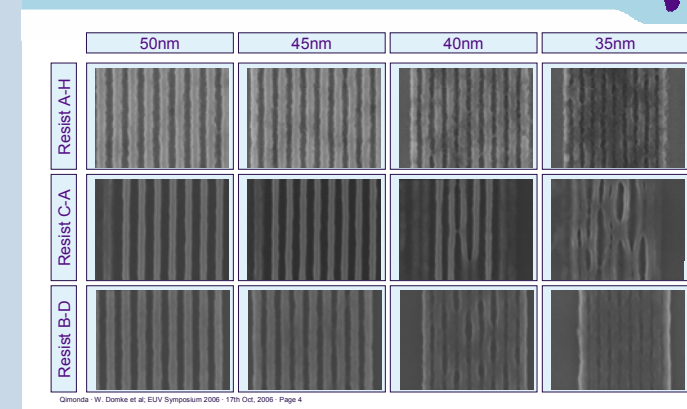


Resist Screening I

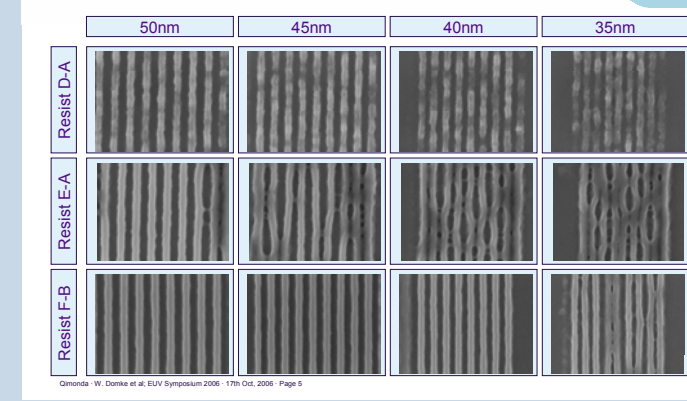
Experimental

- Resist screening has been performed at the ALS/MET, Berkeley in 2H2005
- Optics: 5x reduction Schwartzschild (NA=0.3; 600 x 200 μm field)
- mask: Sematech MET-3, 70nm Cr-absorber
- illumination: monopole 0.6 sigma for ultimate resist resolution & dipole 45 deg.; annular 0.3-0.6 sigma for process windows
- resist: more than 20 samples of various suppliers
- process: 4" wafers with BARC/HMDS for adhesion purposes only, film thickness ~ 80nm, post coat delay < 1h, total time in vacuum 1-2 h, post exposure delay < 1 min, 1x45s puddle development (2,38% TMAH) and DI rinse

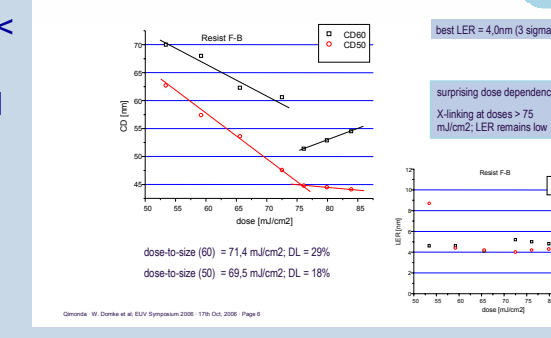
Ultimate resolution, monopole illumination



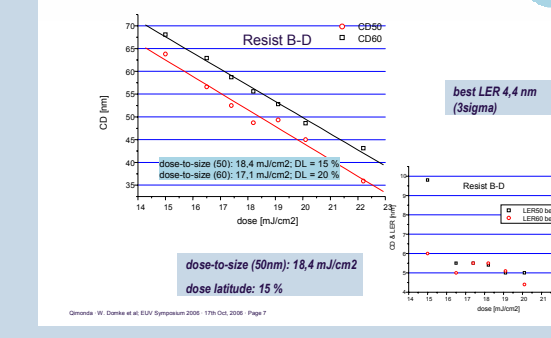
Ultimate resolution, monopole illumination (cont'd)



Low-sensitivity resist F-B shows best LER and the effect of X-linking on CD



Mid-sensitivity resist B-D shows best LER-dose combination



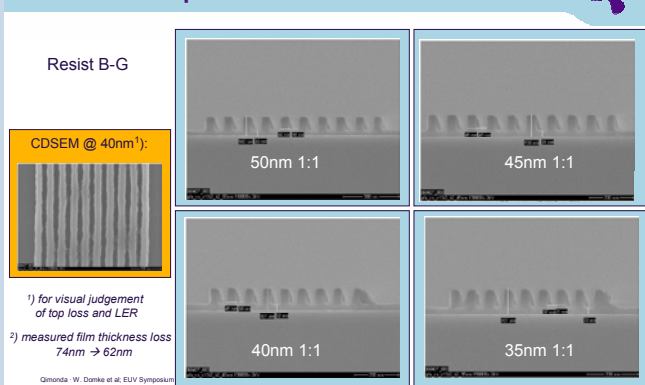
Summary of Resist Screening I (1H2005)

| Resist | LER [nm] | Sens [mJ/cm²] | Resol [nm] | Process Window [nm] | Top Line Adhesion | Pattern Collapse | Outgassing |
|------------|----------|---------------|------------|---------------------|-------------------|------------------|------------|
| Resist B-D | 4.4 | 11.1 | 35 | 184 | 151 | 183 | 18% |
| Resist A-F | 8.3 | 8.4 | 35 | 141 | 141 | 141 | 18% |
| Resist A-D | 8.0 | 10.7 | 35 | 184 | 184 | 184 | 18% |
| Resist E-A | 3.7 | 48.3 | 35 | 141 | 141 | 141 | 18% |
| Resist F-B | 4.1 | 11.4 | 35 | 141 | 141 | 141 | 18% |
| Resist C-A | 8.0 | 10.8 | 35 | 111 | 111 | 111 | 18% |
| Resist C-A | 3.8 | 27.3 | 35 | 141 | 141 | 141 | 18% |

Resist Screening II

- Resist suppliers with most promising Round I results were approached to submit improved resist samples
- 10 samples of three suppliers were tested for improved sensitivity, LER and resolution
- Experimental settings are as in Screening I
- Significant improvements were seen over the last half a year
 - all resist showed resolution down to 35nm 1:1
 - all resists had a dose of size of < 15 mJ/cm²

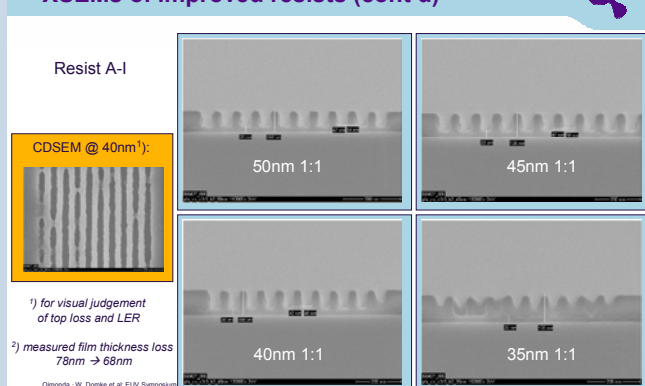
XSEMs of improved resists



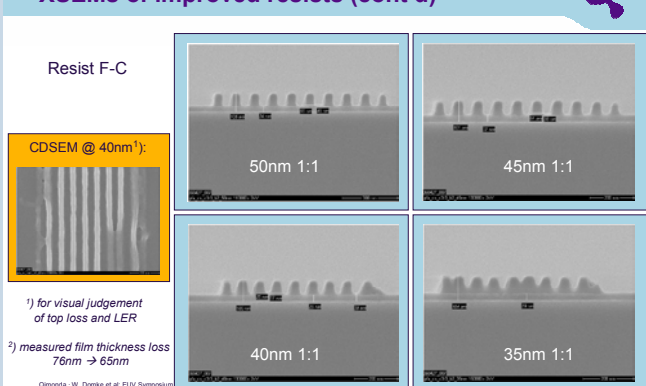
XSEMs of improved resists (cont'd)



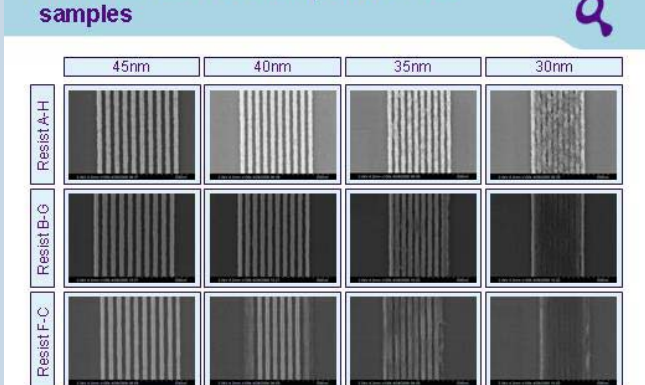
XSEMs of improved resists (cont'd)



XSEMs of improved resists (cont'd)



Ultimate resolution of improved resist samples



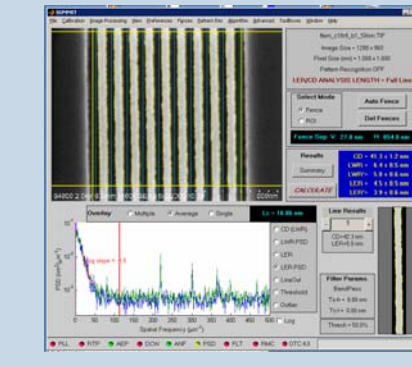
Status of alpha resist ranking: summary of resist screening 2006

| | Resist A-I | Resist A-H | Resist B-G | Resist F-C |
|-------------------------|------------|------------|----------------------------|----------------------------|
| Resolution | 35nm | 35nm | 35nm | 35nm |
| Line Edge Roughness | > 5 nm | > 5 nm | 3.8 - 4.4 nm ¹⁾ | 3.3 - 4.0 nm ²⁾ |
| Process Window | + | 0 | + | + |
| Dose-to-size (90nm 1:1) | ~ 5mJ/cm² | ~ 5mJ/cm² | ~ 15mJ/cm² | ~ 10mJ/cm² |
| Top Line Adhesion | + | 0 | + | + |
| Pattern Collapse | + | + | + | + |
| Outgassing | good | passed | passed | passed |

¹⁾ negative tone resist
²⁾ minimum filtered and un-filtered LER in center of process window

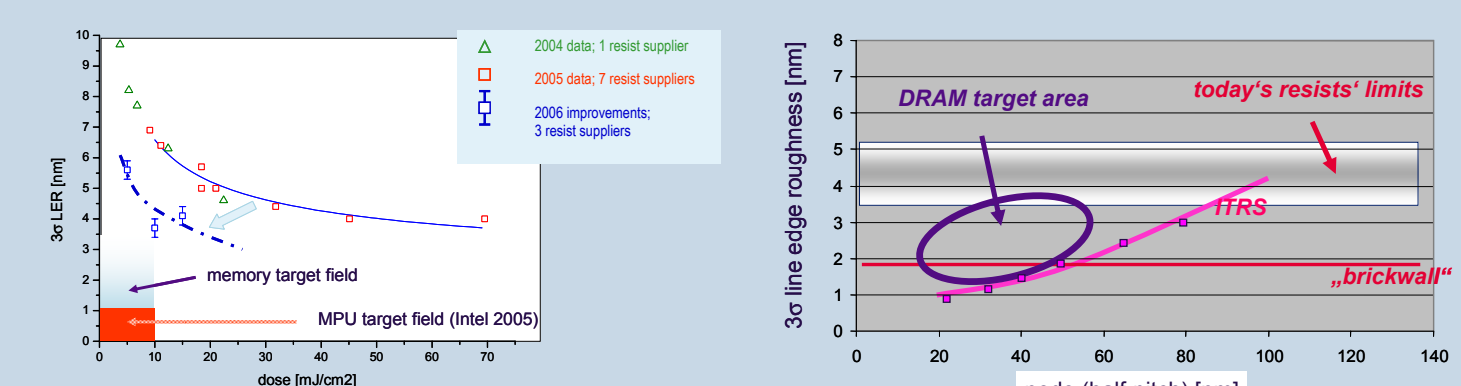
LER determination and DRAM LER specs

- LER is a 3σ value of the deviation from an ideal line edge, assumed to be normally distributed
- for independent line edges $LWR = \sqrt{2} LER$
- LER/LWR data were determined with SUMMIT software (both lines and contacts; see fig.)
- While MPU gates for the 32nm node are ~ 21nm the gate lengths in memory support devices are ~ twice that gate lengths
- LER specs for DRAM are more relaxed than for MPU



Summary and Conclusions

- More than 30 resists (Round I & II) have been screened at the Berkeley ALS/MET for their ultimate resolution, process window and LER behavior.
- Amongst the positive tone resist samples one negative tone resist system showed good performance. Negative systems are well suited to deal with high-flare.
- LER/sensitivity behaviour is still dominated by shot noise.
- the low-sensitivity limit of LER is now approaching 2 nm, which is a "brickwall" – a molecular limit in terms of polymer coil size. According to the ITRS2005, this limit will be reached at the 50nm node.
- Resist suppliers have improved their latest resist formulations towards a resolution ≤ 35nm, sensitivity < 15 mJ/cm² and LER ≤ 4nm; moving towards a molecular LER limit of beyond 2 nm.
- The ITRS LER specs for the sub-50nm nodes are still beyond that molecular LER limit
- For MPU manufacturers it seems extremely challenging to reach the LER target due to the molecular limits of today's resists. The more relaxed requirements for memory put the LER goal for the sub-40nm nodes better into reach.



Comparison of 2004-2005-2006 resist data

LER requirements for DRAM are not as strict as ITRS

Acknowledgements

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