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Required resist and tool performance for 32nm, 22nm, and 16nm HP HVM using EUVL

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Use of K_{LUP}

- K_{LUP} is a photoresist Figure of Merit that indicates how well a resist is performing in terms of Resolution, Sizing dose, and Line Width Roughness (simultaneously!)
- K_{LUP} independent of
  - Optical contrast, illumination conditions, exposure tool
  - Pattern density (pitch)
  - Processing conditions
- Hence, it is a true photoresist Figure of Merit
- It is calculated by the formula

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

- More details on KLUP, see SPIE paper 6519-31 (2007)

Conditions K_{LUP} calculations

- K_{LUP} calculations were performed for pitches 64nm, 44nm, 32nm
- Assumed NILS = 3 for all cases
  - From one node to another, an increase in ILS is assumed in order to keep NILS constant
  - One exception: What happens if NILS = 2?
- Resist thickness scaled with pitch (cf. ITRS)
- LWR targets equal to 10% of half pitch
  - Less aggressive than ITRS!
- EL calculations are based on given optical contrast and taking into account loss of contrast due to acid diffusion
  - Value of L_d is set to 1/3 of the pitch to minimize LWR
  - Actual value of L_d does not influence the K_{LUP} calculations because variation in L_d will have impact on EL also (keeping K_{LUP} constant)
  - L_d must scale with pitch in order to keep contrast loss due to acid diffusion under control (less than <60%)

K_{LUP} for EUV HVM

EUV	p (nm)	λ (nm)	ν (s^{-1})	E_s (mJ/cm^2)	d (nm)	EL	LWR (nm)	L_d (nm)	K_{LUP}	NILS
2009	**64**	13.4	2.24E+16	**29.0**	64	0.12	3.2	21	0.32	3.0
2011	**44**	13.4	2.24E+16	**60.0**	44	0.12	2.2	14.7	0.32	3.0
2013	**32**	13.4	2.24E+16	**115.0**	32	0.12	1.6	10.6	0.32	3.0

A (rows 2009–2013)

A
- Expected sizing dose based on best EUV resist to date (lowest K_{LUP} observed)
  - Note: limited dataset of K_{LUP} for EUV resists so far
- Other assumptions see previous slide

Increasing sizing doses dictated by tighter LWR target and reduced number of photons per pitch

K_{LUP} for EUV HVM

	EUV	p (nm)	λ (nm)	ν (s^{-1})	E_s (mJ/cm^2)	d (nm)	EL	LWR (nm)	L_d (nm)	K_{LUP}	NILS
A	2009	**64**	13.4	2.24E+16	**29.0**	64	0.12	3.2	21	0.32	3.0
A	2011	**44**	13.4	2.24E+16	**60.0**	44	0.12	2.2	14.7	0.32	3.0
A	2013	**32**	13.4	2.24E+16	**115.0**	32	0.12	1.6	10.6	0.32	3.0
B	2009	**64**	13.4	2.24E+16	10.0	64	0.12	3.2	21	**0.19**	3.0
B	2011	**44**	13.4	2.24E+16	10.0	44	0.12	2.2	14.7	**0.13**	3.0
B	2013	**32**	13.4	2.24E+16	10.0	32	0.12	1.6	10.6	**0.10**	3.0

B

- K_{LUP} target given the dose requirement of 10mJ/cm2
- Other assumptions see slide 3

K_{LUP} needs about a factor 1.5 improvement by 32nm HP and a factor two by 16nm HP

K_{LUP} for EUV HVM

	EUV	p (nm)	λ (nm)	ν (s^{-1})	E_s (mJ/cm²)	d (nm)	EL	LWR (nm)	L_d (nm)	K_{LUP}	NILS
A	2009	**64**	13.4	2.24E+16	**29.0**	64	0.12	3.2	21	0.32	3.0
A	2011	**44**	13.4	2.24E+16	**60.0**	44	0.12	2.2	14.7	0.32	3.0
A	2013	**32**	13.4	2.24E+16	**115.0**	32	0.12	1.6	10.6	0.32	3.0
B	2009	**64**	13.4	2.24E+16	10.0	64	0.12	3.2	21	**0.19**	3.0
B	2011	**44**	13.4	2.24E+16	10.0	44	0.12	2.2	14.7	**0.13**	3.0
B	2013	**32**	13.4	2.24E+16	10.0	32	0.12	1.6	10.6	**0.10**	3.0
C	2009	**64**	13.4	2.24E+16	10.0	64	0.12	3.2	21	**0.19**	3.0
C	2011	**44**	13.4	2.24E+16	20.0	44	0.12	2.2	14.7	**0.19**	3.0
C	2013	**32**	13.4	2.24E+16	30.0	32	0.12	1.6	10.6	**0.16**	3.0

C

- K_{LUP} target given a dose requirement of 10mJ/cm² for 32nm HP, 20mJ/cm² for 22nm HP, 30mJ/cm² for 16nm HP
- Other assumptions see slide 3

K_{LUP} needs factor 1.5 improvement by 32nm HP and is then more or less OK given that dose increases and NILS remains constant

Note: LWR based on shot noise scaling only! No intrinsic material LWR is taken into account. See remark last slide

K_{LUP} for EUV HVM

	EUV	p (nm)	λ (nm)	ν (s^{-1})	E_s (mJ/cm^2)	d (nm)	EL	LWR (nm)	L_d (nm)	K_{LUP}	NILS
A	2009	**64**	13.4	2.24E+16	**29.0**	64	0.12	3.2	21	0.32	3.0
	2011	**44**	13.4	2.24E+16	**60.0**	44	0.12	2.2	14.7	0.32	3.0
	2013	**32**	13.4	2.24E+16	**115.0**	32	0.12	1.6	10.6	0.32	3.0
B	2009	**64**	13.4	2.24E+16	10.0	64	0.12	3.2	21	**0.19**	3.0
	2011	**44**	13.4	2.24E+16	10.0	44	0.12	2.2	14.7	**0.13**	3.0
	2013	**32**	13.4	2.24E+16	10.0	32	0.12	1.6	10.6	**0.10**	3.0
C	2009	**64**	13.4	2.24E+16	10.0	64	0.12	3.2	21	**0.19**	3.0
	2011	**44**	13.4	2.24E+16	20.0	44	0.12	2.2	14.7	**0.19**	3.0
	2013	**32**	13.4	2.24E+16	30.0	32	0.12	1.6	10.6	**0.16**	3.0
D	2009	**64**	13.4	2.24E+16	10.0	64	0.08	3.2	21	**0.13**	2.0
	2011	**44**	13.4	2.24E+16	20.0	44	0.08	2.2	14.7	**0.13**	2.0
	2013	**32**	13.4	2.24E+16	30.0	32	0.08	1.6	10.6	**0.11**	2.0

D

- K_{LUP} target given a dose requirement of $10mJ/cm^2$ for 32nm HP, $20mJ/cm^2$ for 22nm HP, $30mJ/cm^2$ for 16nm HP
- NILS dropped to 2
- Other assumptions see slide 3

K_{LUP} needs factor 2.5 improvement by 32nm HP and is then more or less OK given that dose increases

Important Note

- K_{LUP} is an empirical parameter that includes all contributions to LWR
  - Shot noise scaling and deprotection statistics
  - Material contributions to LWR
- When using K_{LUP} for extrapolation (as in this presentation), we assumed that all of the LWR is caused by shot noise effects (statistics on number of photons *and* deprotection chemistry)
  - It assumes LWR caused by the material is zero
  - It assumes LWR can go to zero in case of extremely high exposure dose and NILS
  - Reason for not implementing intrinsic material LWR is uncertainty about size of it (3σ); values reported range from 1 to 3nm.
- If the inherent material contribution to LWR would be e.g. 1.5nm (3σ), the LWR may never go below that value and the validity of this extrapolation stops at 1.5nm LWR (or even slightly above).
- This extrapolation hence gives the 'best case scenario' (no material LWR).

- *For current evaluations, LWR is in the range of 4.5-10nm. The shot noise/deprotection statistics scaling in current experiments is clearly present and material contribution to LWR is smaller*