Cost of 45nm Lithography

193nm Immersion Lithography and Alternatives

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Agenda

- Definition of 45nm node
- Comparison of lithographic techniques for the 45nm node.
  - *Processing window*
  - *Feasibility*
  - *Cost*
- Conclusion

Generic Definition of Technology Nodes

Poly	1/2 Pitch	Line	Pitch 1	Pitch 2	Pitch 3
Node	1	1/2 Pitch next node	2.0	2.5	3.0
65	90	65	180.0	225.0	270.0
45	65	45	130.0	162.5	195.0
32	45	32	90.0	112.5	135.0
22	32	22	64.0	80.0	96.0

Contact	1/2 Pitch	Hole	Pitch 1	Pitch 2	Pitch 3	Pitch 4	Pitch 5
Node	1	1.0	2.0	2.5	3.0	4.0	5.0
65	100	100	200.0	250.0	300.0	400.0	500.0
45	70	70	140.0	175.0	210.0	280.0	350.0
32	50	50	100.0	125.0	150.0	200.0	250.0
22	35	35	70.0	87.5	105.0	140.0	175.0

Metal	1/2 Pitch	Line	Pitch 1	Pitch 2	Pitch 3	Pitch 4	Pitch 5
Node	last node	1.0	2 (1:1)	2.5 (1:1.5)	3 (1:2)	2.5 (1.5:1)	3 (2:1)
65	90	90	180.0	225.0	270.0	225.0	270.0
45	65	65	130.0	162.5	195.0	162.5	195.0
32	45	45	90.0	112.5	135.0	112.5	135.0
22	32	32	64.0	80.0	96.0	80.0	96.0

Imaging Light, Reflecting Light, and Stray Light

Mask

Spatial frequencies
diffracted from Mask

Imaging lens contributes to
system straylight induced by
light from either direction

Specular reflections

Photoresist

Recombining filtered
spatial frequencies

Wafer

Contrast of the Transmitted Image

TE 3 beams

TE 2 beams

1.0

0.5

0.0

-0.5

-1.0

Contrast

Unpo 2 beams

Unpo 3 beams

TM 3 beams

TM 2-beam
Recombination

0 0.2 0.4 0.6 0.8 1

λ / 2P

Reflection from the Resist Interface

Reflection Intensity

1
0.8
0.6
0.4
0.2
0

TM dry
TE dry
TM immersion
TE immersion

$n_1:n_2=1:1.75$

$n_1:n_2=1.46:1.75$

0
0.2
0.4
0.6
0.8
1

sin(Theta)

The Effects of Stray Light

DOF(um)

0.6
0.5
0.4
0.3
0.2
0.1
0

0.5 0.6 0.7 0.8 0.9 1

Sin(Theta)

no PDS

193nm Immersion
or 132nm Dry
no SSL, no PDS

132nm Dry
SSL, PDS

193nm
Immersion
SSL, PDS

157nm Dry
no SSL
no PDS

SSL, no PDS

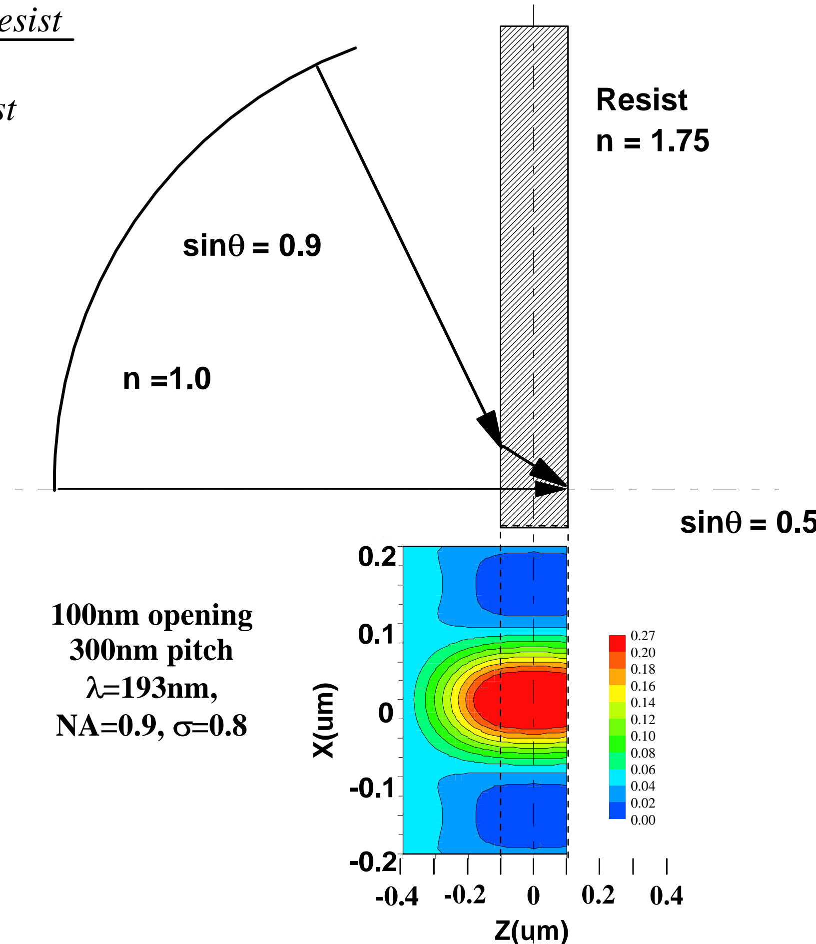
SSL, PDS

PDS from 157nm, and 132nm dry, as well as 193 immersion, 65nm lines, 65nm openings, σ=0.82, 8% exposure latitude, n_{water}=1.46, n_{resist}=1.75, CD tolerance = ± 10%, SSL=10%.

Available DOF

$$\frac{DOF_{available}}{n_{coupling\ medium}} = \frac{DOF_{diffract}}{n_{coupling\ medium}} - \frac{THK_{resist}}{n_{resist}}$$

$$DOF_{available} = DOF_{diffract} - \frac{n_{coupling\ medium}}{n_{resist}} THK_{resist}$$



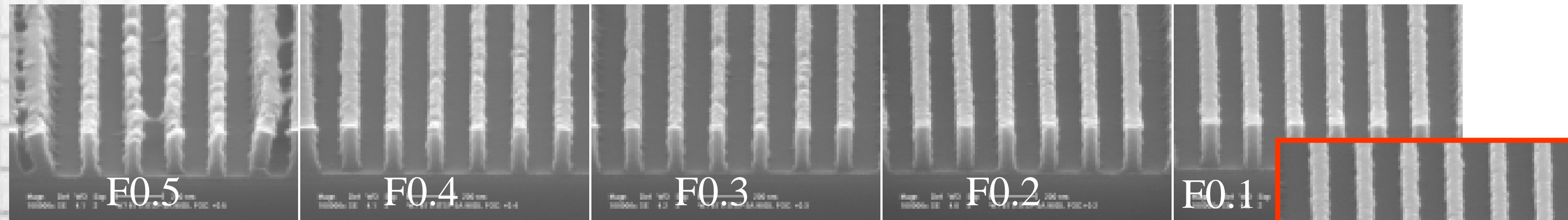
Simulated Example on $DOF_{diffract}$ and DOF_{avail}

Resist thk(nm) 200 n_{resist} 1.75 n_{CM} 1.44

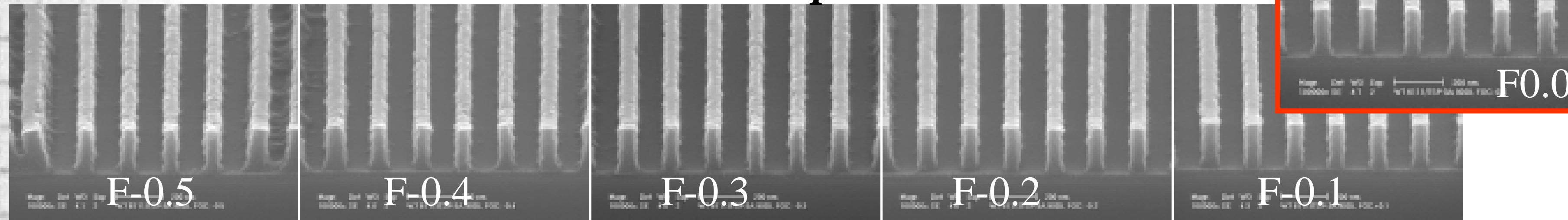
λ (nm)	System	$\sin\theta$	k_1	k_3	DOF_{diff}	DOF_{avail}
193	dry	0.900	0.466	0.350	240	125
134	immer-sion	0.625	0.466	0.367	445	280
134	dry	0.625	0.466	0.358	434	320

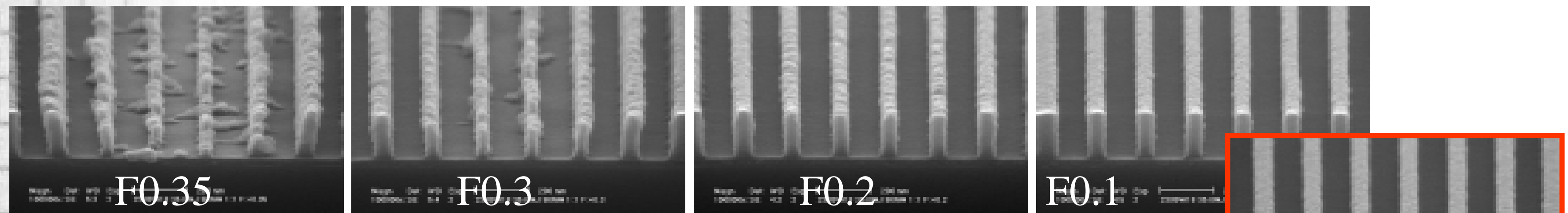
100 nm line opening, 300 nm pitch, σ=0.8

Immersion Imaging Result from ASML



Immersion exposure





Dry exposure

F-0.25
F-0.2
F-0.1

k_1=0.35
90nm dense
lines 225nm
thick

DOF_{avail} of the Poly, Contact, and Metal layers for the 45-nm nodes.

Poly 150nm resist
Contact 175nm resist
Metal 175nm resist

Less P3
Less P4,P5
P1-P3 ± 5nm, P4,P5 ± 6nm

Available DOF (nm)

350
300
250
200
150
100
50
0

157 Att
193I Att
157 AttTE
193I AttTE
193 ALT
157 ALT
193I ALT
157 ATT
193I ATT
193I BIM
193I Att
193I Att
193 BIM
157 BIM
193I BIM

Cost / Wafer Pass

Normalized Cost/Pass

2
1.5
1
0.5
0

Maintenance
Consumable
Acquisition

1.66
0.67
0.89

1.08
0.29
0.74

1
0.28
0.67

0.5
0.12
0.36

248nm
193nm dry
193nm Imm
157nm

Tool

Components of Cost

Costs	248nm	193nm dry	193nm Immersion	157nm
Acquisition	Exposure tool cost, hook up, space	Cost difference mostly in lens and laser. Some due to better tool spec.	Cost difference mostly in immersion head and water handling	Cost difference in lens and nitrogen flushing
Consumable	Resist, laser pulses, developer, filters, etc	Cost difference in resist, laser pulses, and filters	Cost difference mostly in resist	Cost difference in resist, laser pulses, filters, and nitrogen
Maintenance	Spare parts, scheduled maintainence contamination prevention, labor, etc.	Cost difference in spare parts and prevention of contamination	Cost difference in water handling	Cost difference in contamination prevention and nitrogen handling
Masks not yet factored in	Blanks, patterning, inspection, repair, pellicle	Cost delta in blanks	Same as 193nm dry tool	Cost delta would be in pellicles, blanks, and repair

Processing Considerations

Processing Considerations	193nm dry	193nm Immersion	157nm
Poly	Need alternating PSM. Higher cost due to double exposure, masks, and software licensing. There is design restriction	Can use attenuated PSM with annular illumination	Need TE illumination, design restriction, or alternating PSM
Contact / Via	Insufficient available DOF	Need to restrict large pitches or relax CD tolerance at these pitches	Need to restrict large pitches or relax CD tolerance at these pitches
Metal Layers	Meets available DOF target	Exceeds available DOF target	Exceeds available DOF target

Challenges

193nm Dry	Severe DOF restriction
193nm Immersion	Defects near wafer edges Shake out at manufacturing environment and throughput
157nm Dry	CaF_2 cost and quality, resists, pellicles, N_2 flushing