Simulation investigation of resolution enhancement techniques (RETs) in low k1 EUV

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ASML

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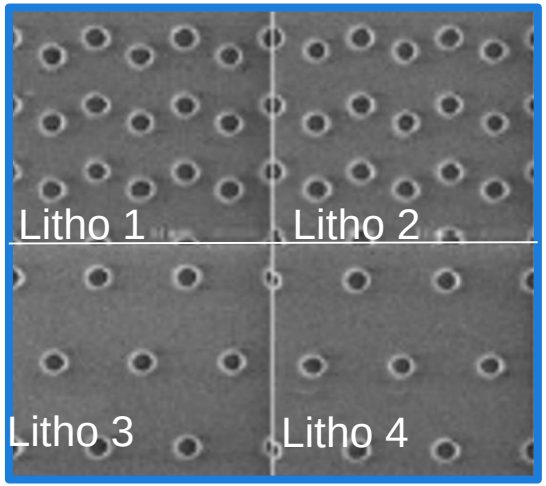
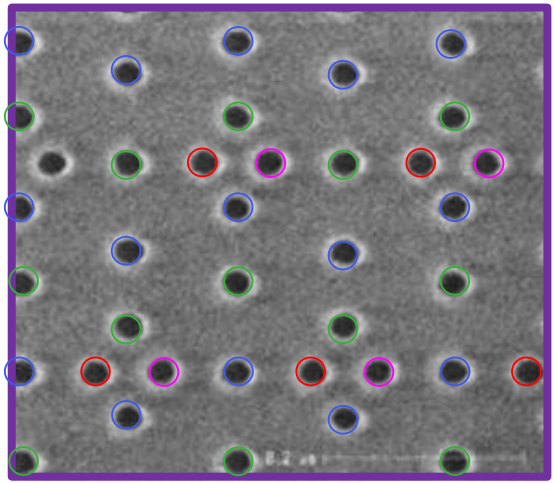
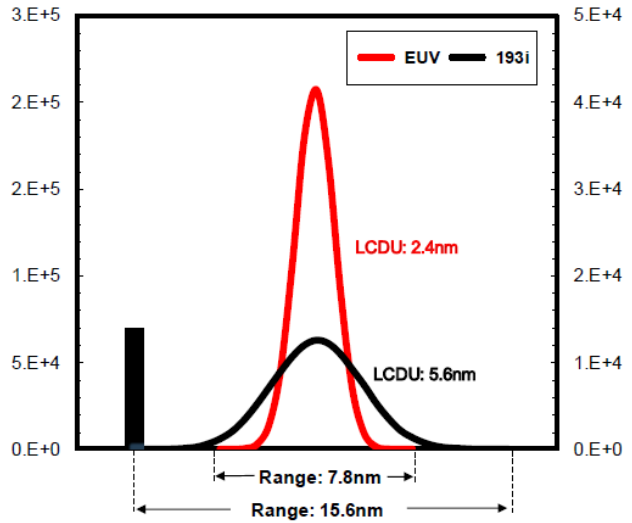
EUV SP vs 193i MP: improve LCDU

Via with 193i multiple patterning (left) vs. EUV single-patterning (right)





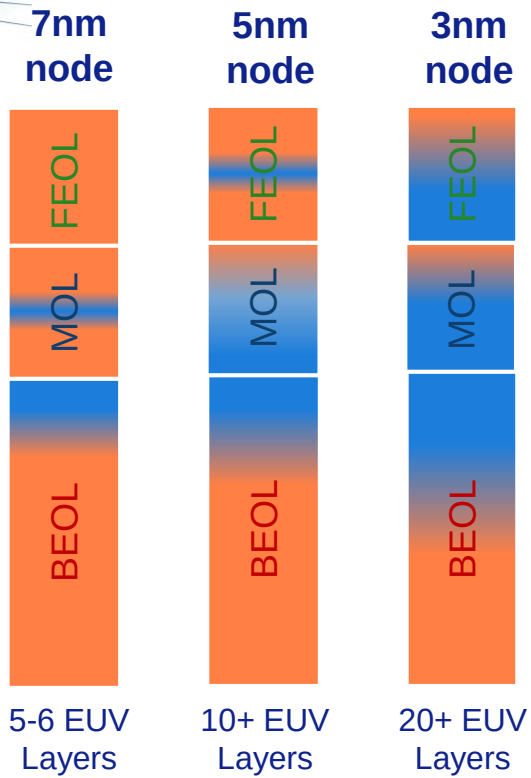


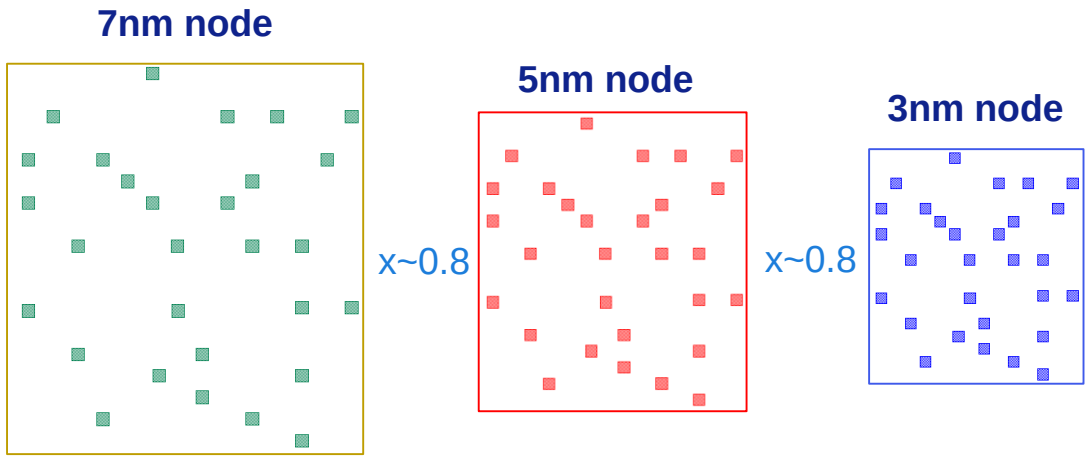
Local Critical Dimension Uniformity (LCDU) and process control of single patterning EUV (Red) vs. multiple-patterning 193i (black) showing 2-3X improvement.

As high volume production requirements had been satisfied by the EUV technology, we started the volume ramp of the enhanced 7nm technology with EUV insertion in 2019. Looking forward, the usage of EUV layers for 5nm technology node and beyond will continue to increase."

S.-Y. Wu (TSMC), "Key Technology Enablers of Innovations in the AI and 5G Era,"
IEDM, San Francisco, 11 December 2019

Trends of EUV layers #'s and Via pitches in Logic IC





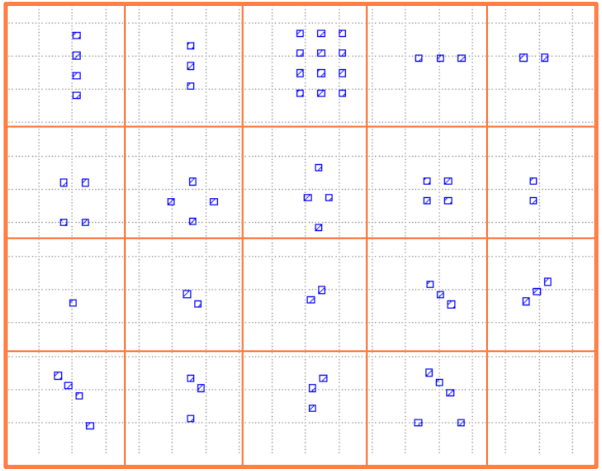
- Our studies indicate that Via pitches shrink by ~20% node to node
  - Current EUV SP could patten vias pitch around 43 – 45nm.
  - How about EUV SP for pitch range from 38 – 44nm
  - EUV SP for Via layers is key to maintaining cost-effectiveness

193 immersion process | EUV process

FEOL: Front End of Line; MOL: Middle of Line; BEOL: Back End of Line

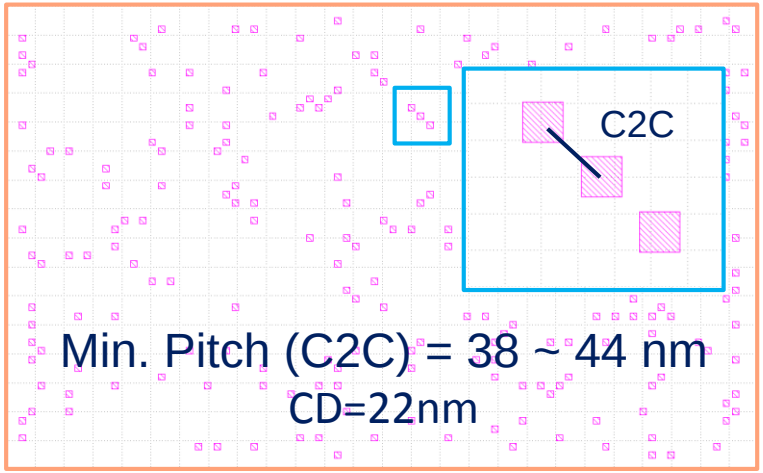
Layout, simulation method and nominal conditions

SMO w/o SRAF



Test Patterns

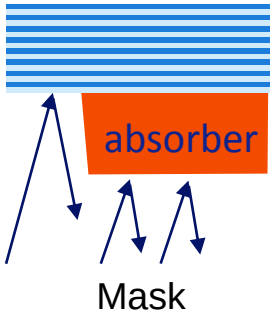
MO w/o SRAF



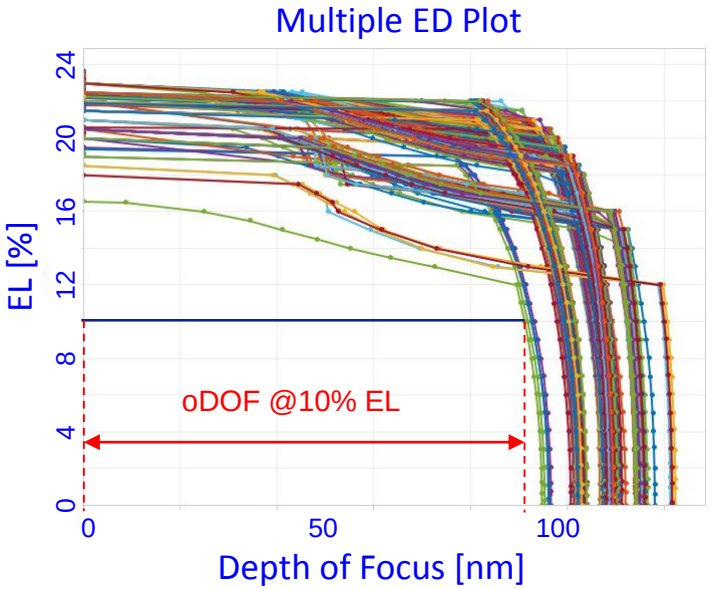
Full Layout

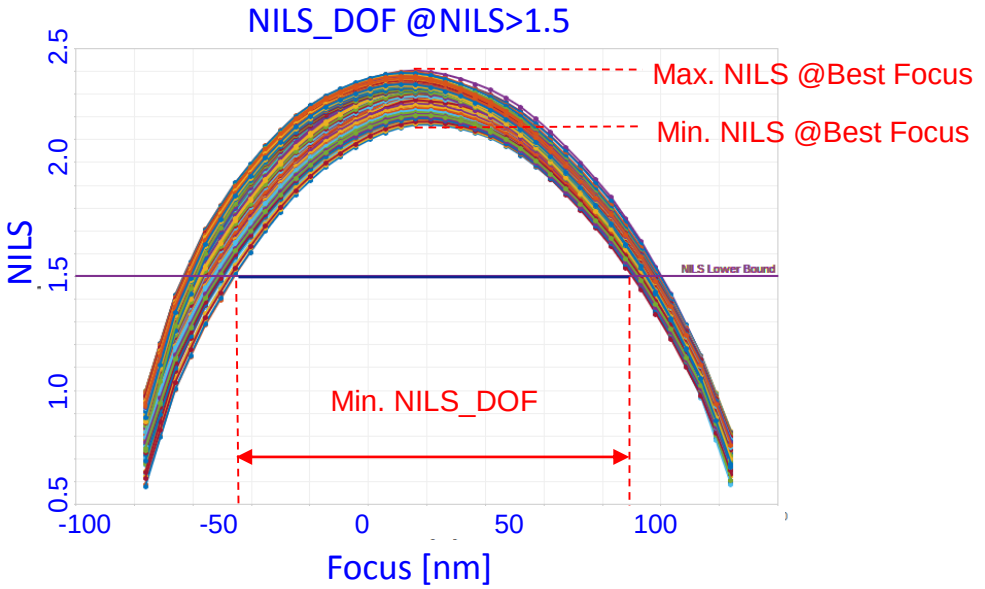
The following conditions are used in simulations

- EUV Scanner: NXE3400X
- Mask: 40x Mo/Si multiple layer with a 55-nm thick Ta-based absorber
- Resist: CAR (30nm)
- Imaging: Dark-field mask with M3D and calibrated resist models



Litho Metrics (oDOF, NILS, NILS_DOF)



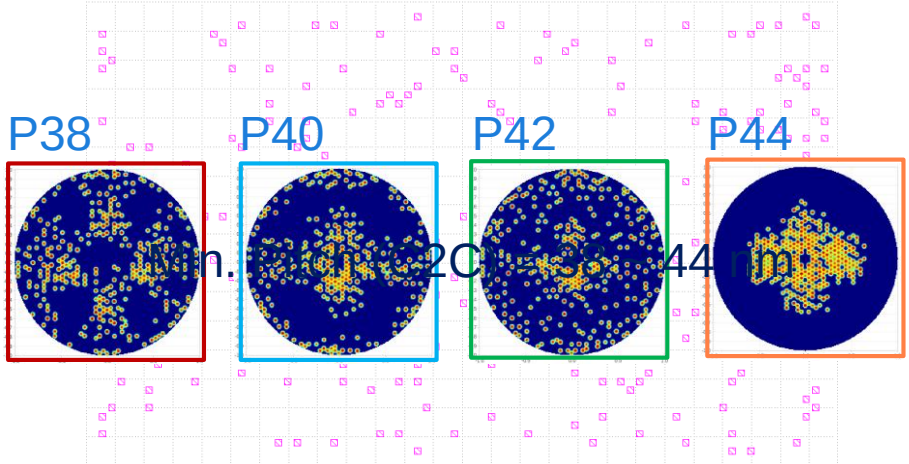


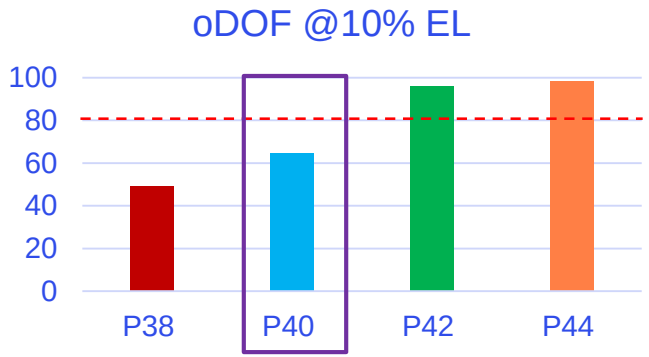
- oDOF (Overlapped DOF) @10% EL = minimum overlap of CD DOF for all 1000 cut lines
- Min. NILS_DOF = minimum overlap of NILS_DOF for all 1000 cut lines
- Min./Max. NILS @Best Focus = minimum/maximum NILS for all 1000 cut lines at Best Focus

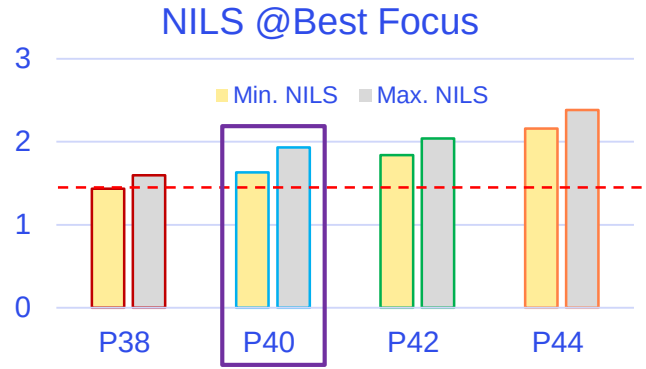
❖ DOF: Depth of Focus . NILS: Nominalized Image-log Slope. EL: Exposure Latitude

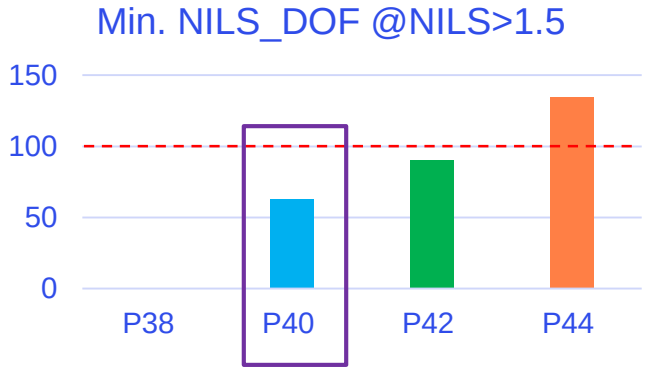
MO results of logic Via vs. min. Pitch (C2C)

Based on Ta absorber



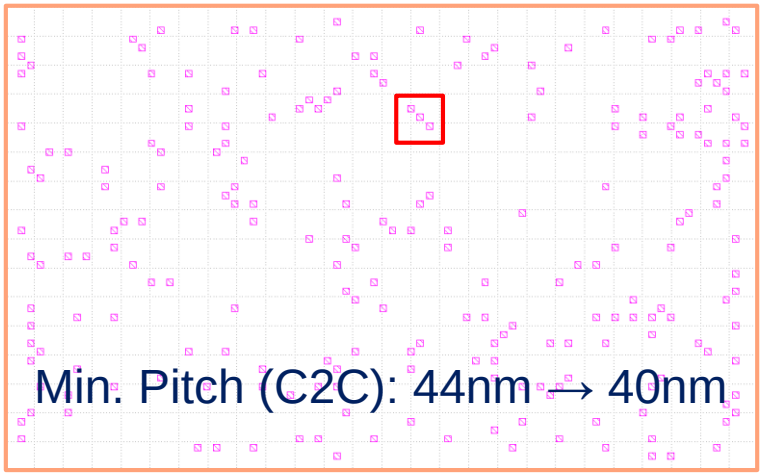


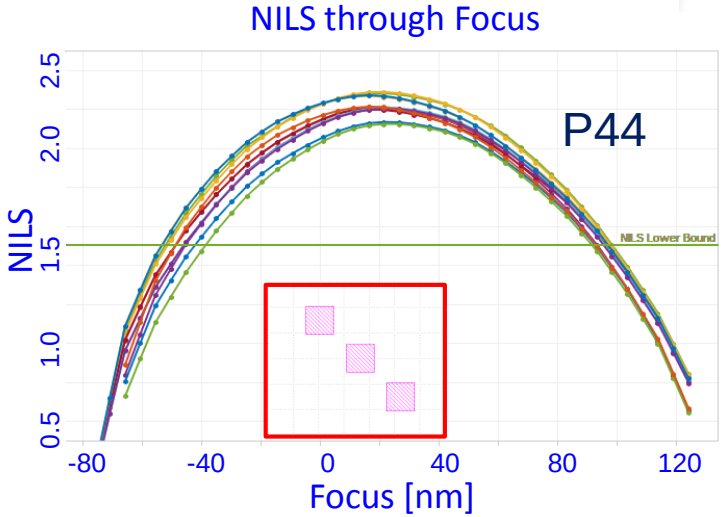




Analysis between Min. Pitch 44nm and 40nm

Based on Ta absorber





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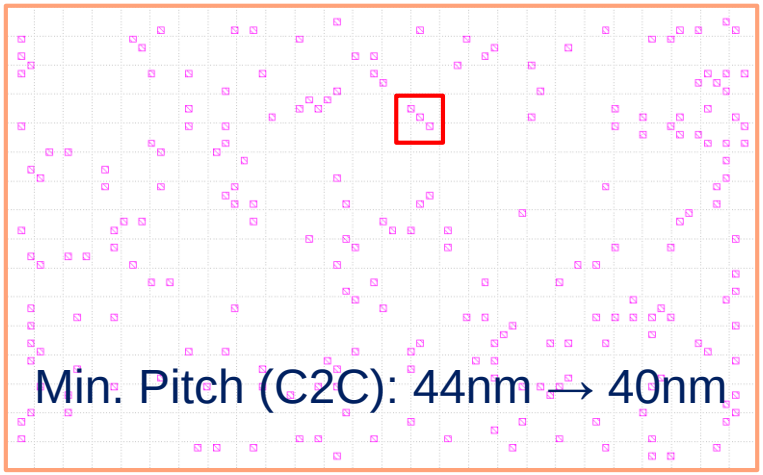
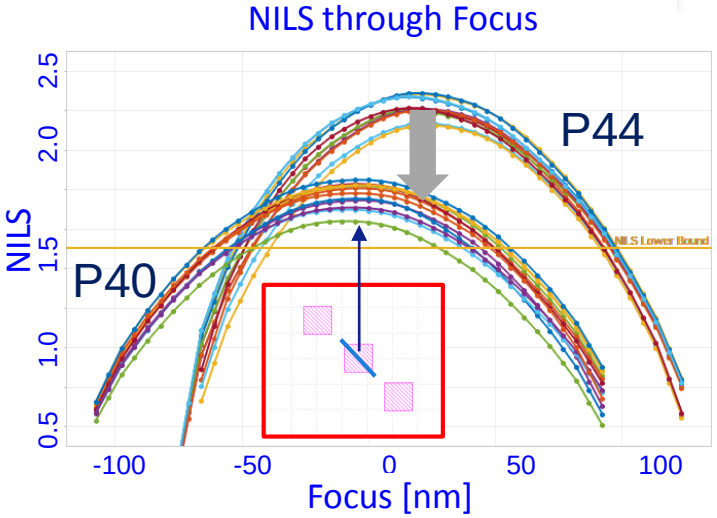
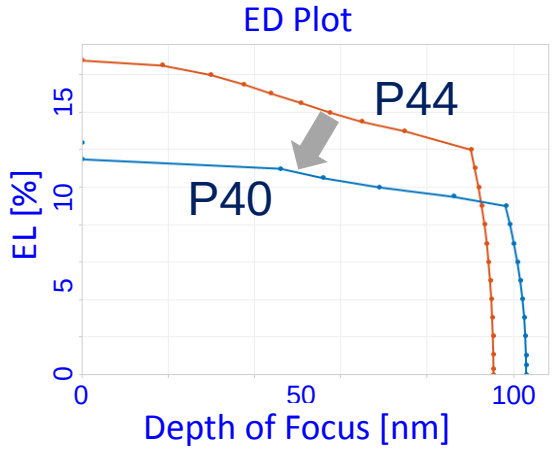
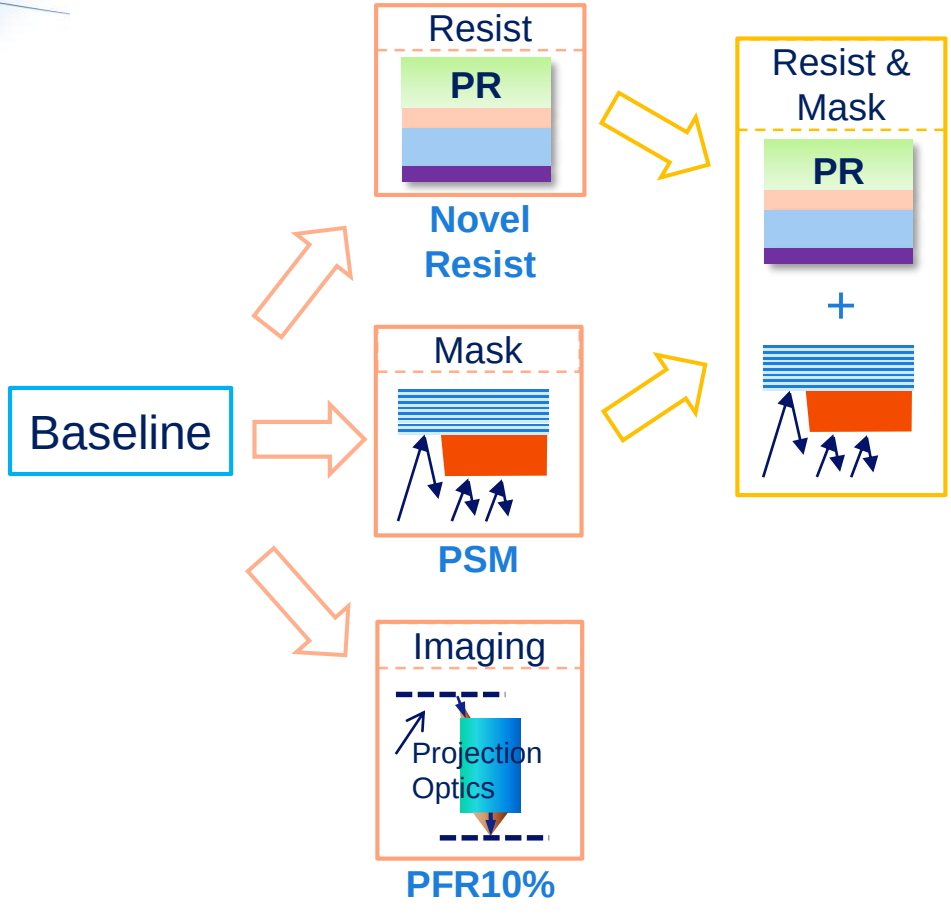


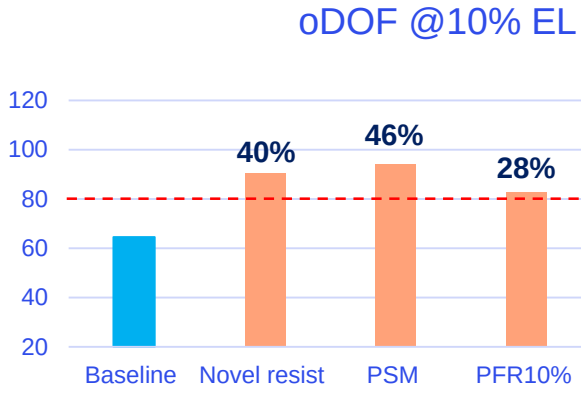


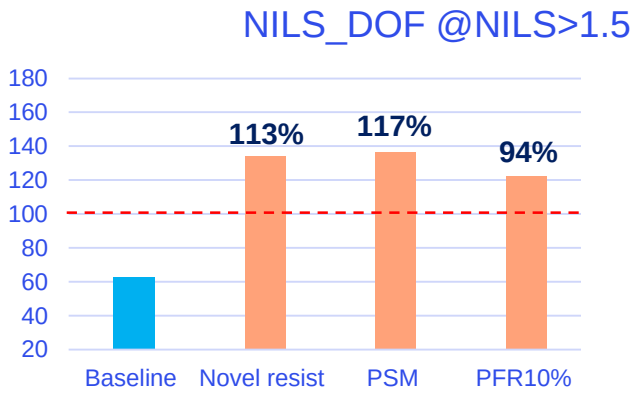
- NILS curve will dramaticaly decrease overall, when Min. Pitch shrunk.
- Diagonal cutline simultaneously limit the oDOF and NILS_DOF.



MO results of RETs for logic Via with min. Pitch=40nm







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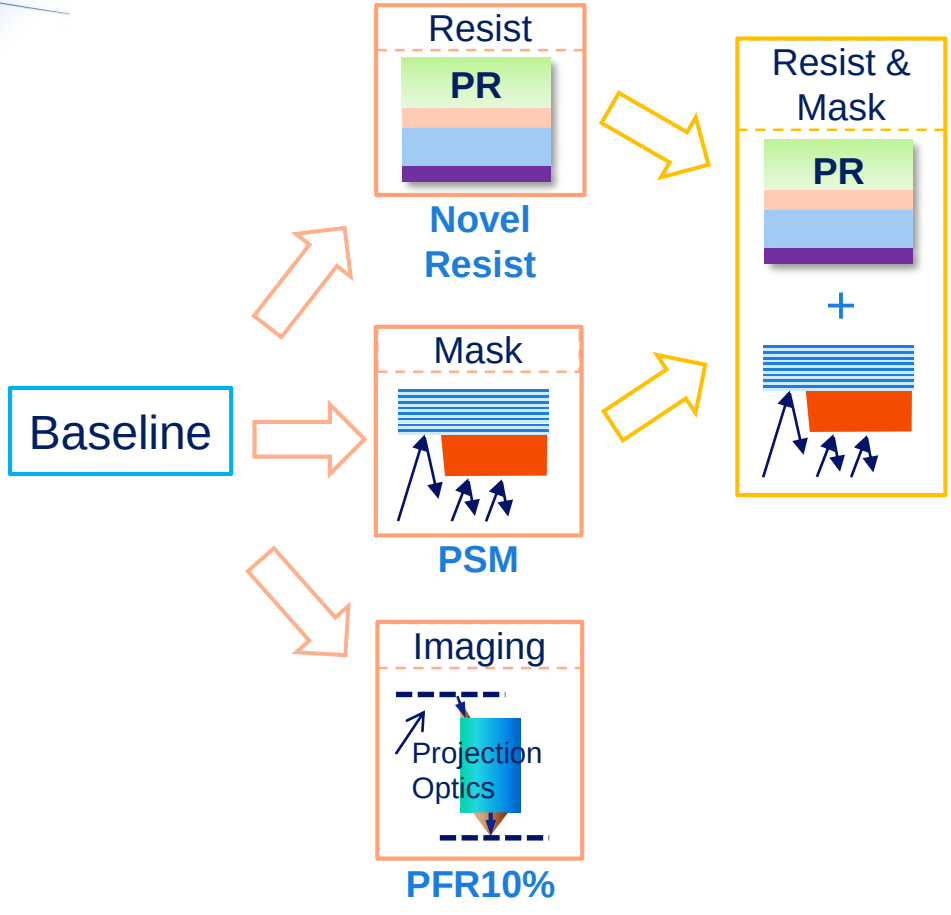

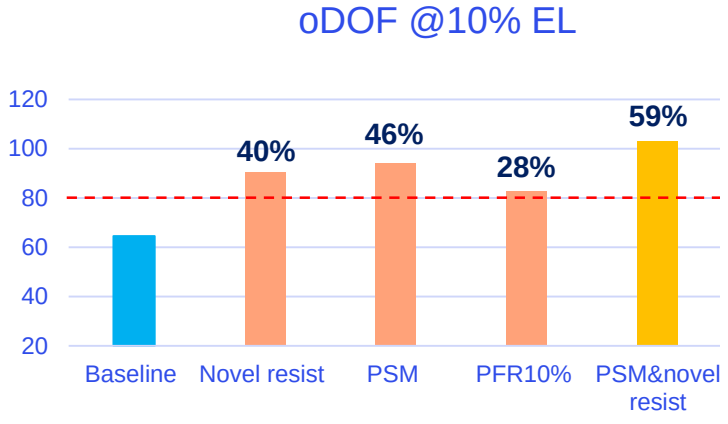

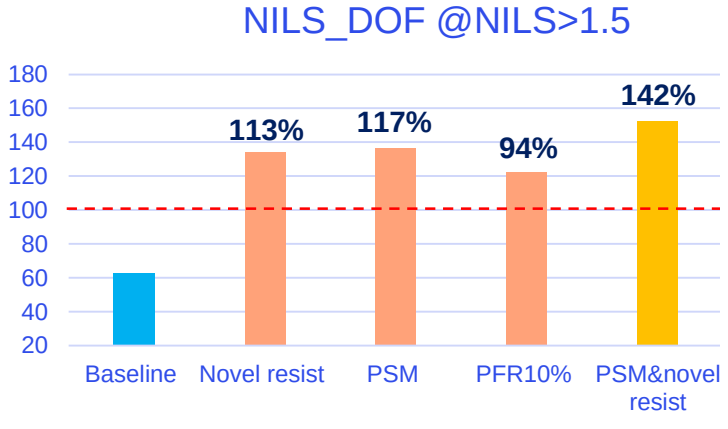

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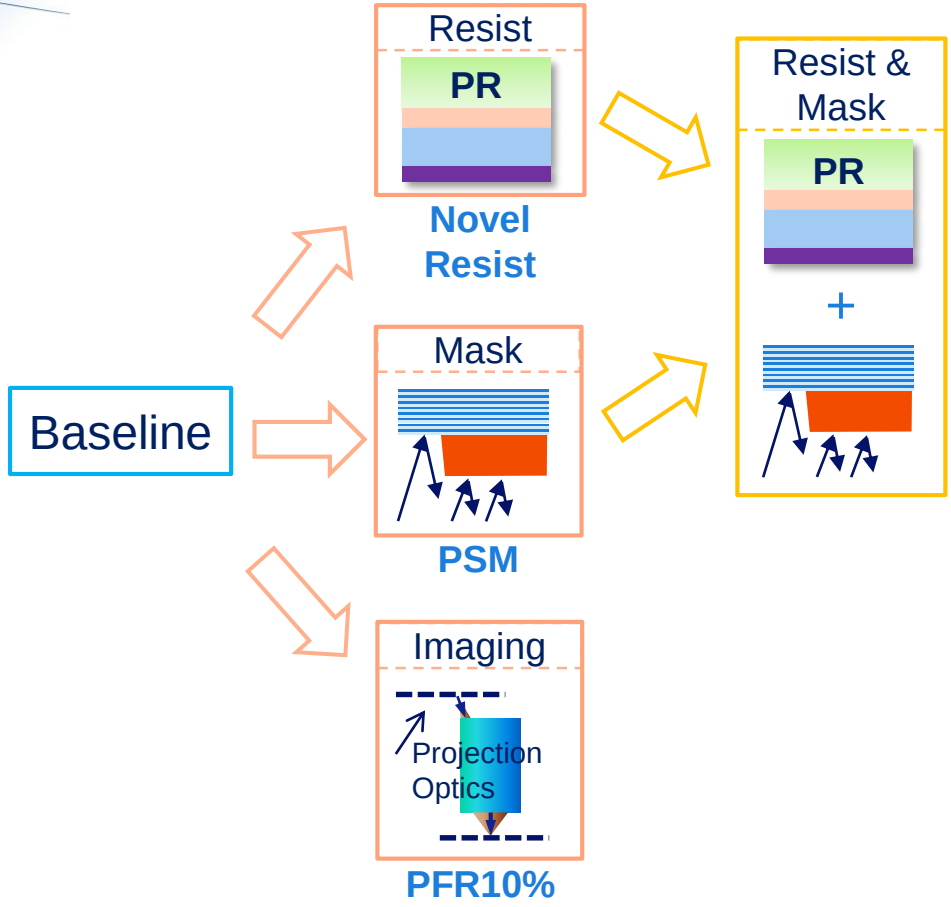
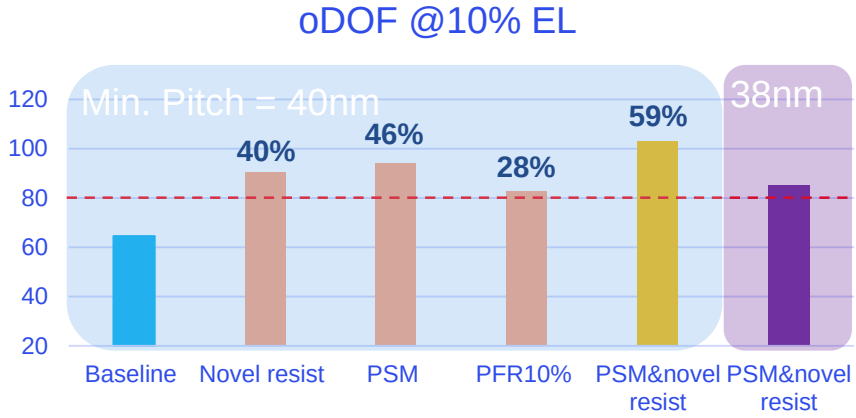
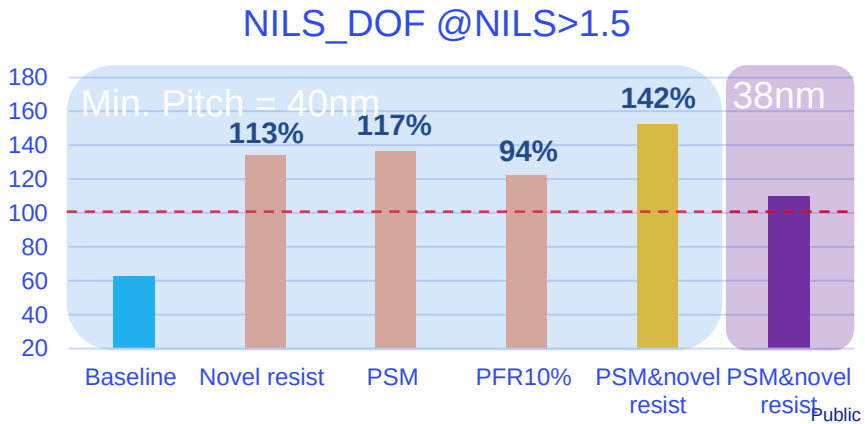






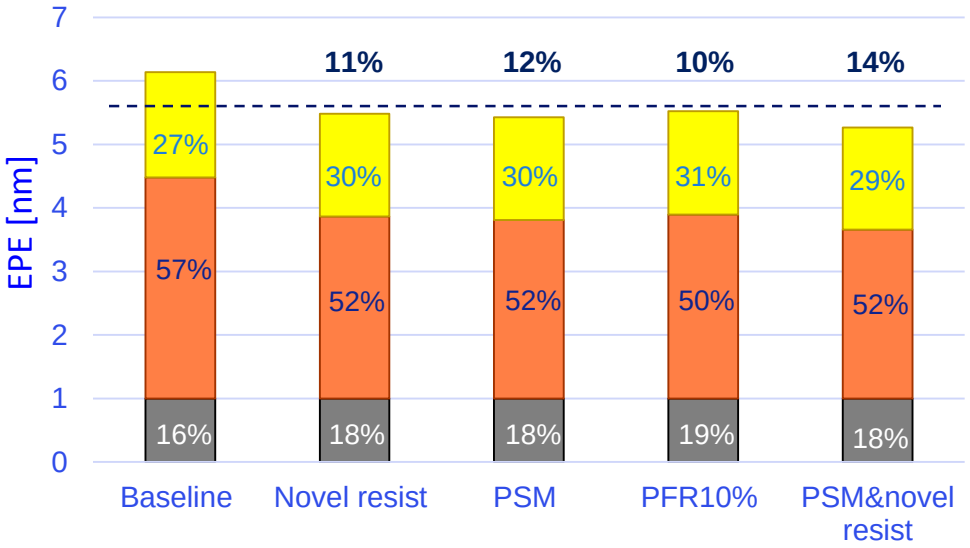
Assessment of Total Edge Placement Error (EPE)

1. *Jan Mulkens et al., SPIE 2017&2018*
2. *Weimin Gao et. al., SPIE 2020*
3. *S. G. Hanssen, JM3 17(1), 2018*

$$\text{Total EPE} = \text{Systematic} + \text{Local} + \text{Global} =$$

$$\frac{(\mathrm{HR_{OPC}} + 3\sigma_{\mathrm{PBA}})}{2} + \frac{6\sigma_{\mathrm{LCDU}}}{\sqrt{2}} + \sqrt{(3\sigma_{\mathrm{OVL}})^2 + \left(\frac{3\sigma_{\mathrm{GCDU}}}{2}\right)^2}$$

EPE ~5.6nm was used as spec. [2]



Error budget range
Focus error: ±35nm
Dose error: ±2%
Mask error: ±0.3nm
Flare error: 2±0.5%

Global CDU

Local CDU

Systematic

OVL: Overlay
PBA: Proximity Bias Average (Scanners CD matching)
HR OPC: Half range of optical proximity correction.
GCDU: Global CDU
LCDU: Local CDU

Conclusion & Future work

Conclusion

- Simulation results show that the current lithographic approach with a standard TaBN absorber does not offer sufficient imaging performance for logic contact patterns of pitch 40nm and below.
- By adopting improved novel resist, PSM or PFR reduction, it can result in a significant increase of oDOF, NILS_DOF, as well as EPE. These techniques could help to extend the 0.33NA EUV SP to pitch 40nm for logic contact patterns.
- Our investigations indicate that for via pitch smaller than 40nm, a combination of RETs is required. Such low k1 EUV requires a combination of multiple RETs including not only novel EUV masks but also advanced imaging techniques, enhanced OPC, high-resolution photoresists.

Future work including investigations of

- SMO/MO with SRAF
- Curvilinear OPC
- Through slit and aberration impact

Thank You

Thanks for helpful and inspiring discussions/support from:

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