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Progress of EUV resists towards high-NA EUV lithography

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IWAPS 2019

Outline

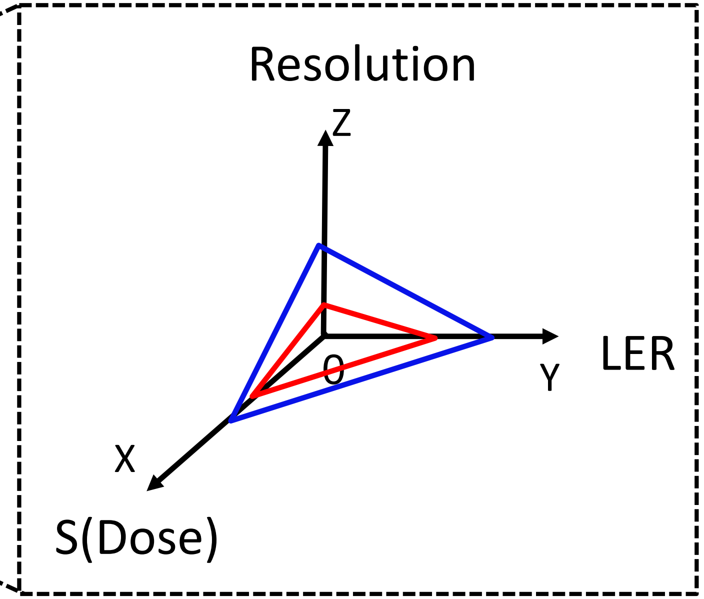
- EUV resist challenges
- EUV Interference lithography (EUV-IL@PSI)
- Highlights of the PSI resist screening program
- How post exposure baking (PEB) and film thickness (FT) influence dose and LWR
- Summary

EUV resist challenges

Challenges:

- Resolution (R, HP in nm), line edge roughness (LER, 3σ in nm) and sensitivity (S, dose in mJ/cm^2): challenging to improve simultaneously

RLS trade-off

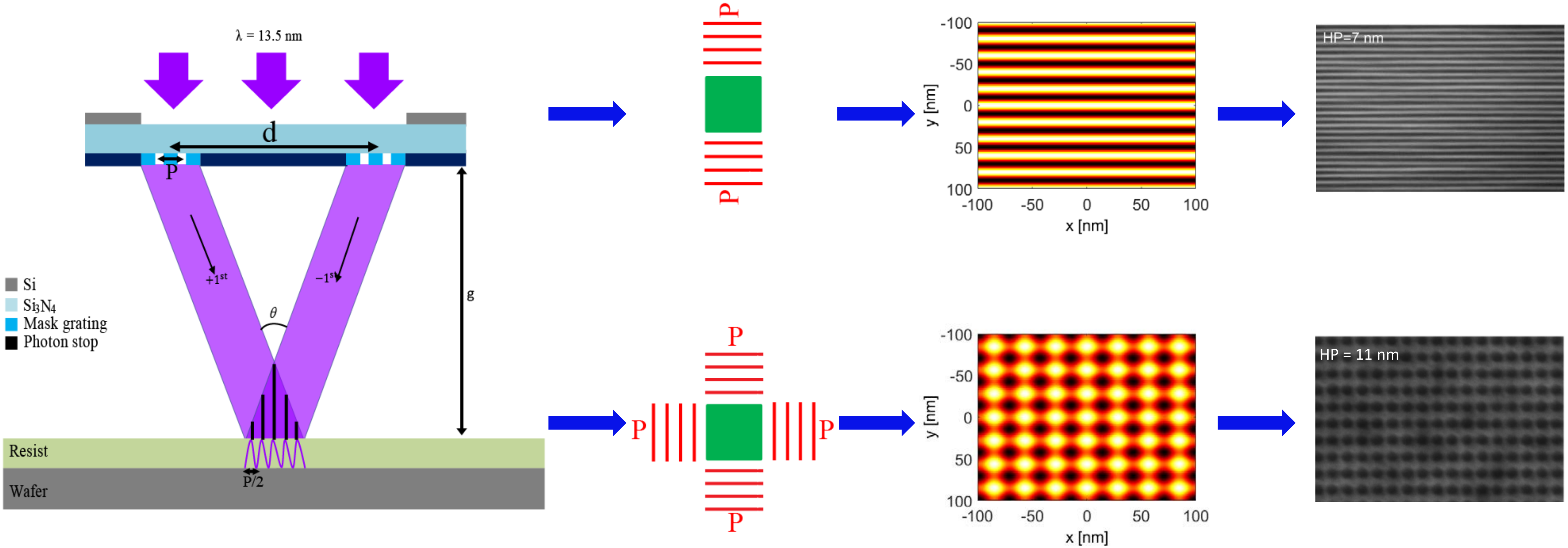


Better LER → high dose (S)

High resolution→ high dose (S)

- Develop better high resolution resist
- Limited access to EUV scanners - expensive EUV resists evaluation

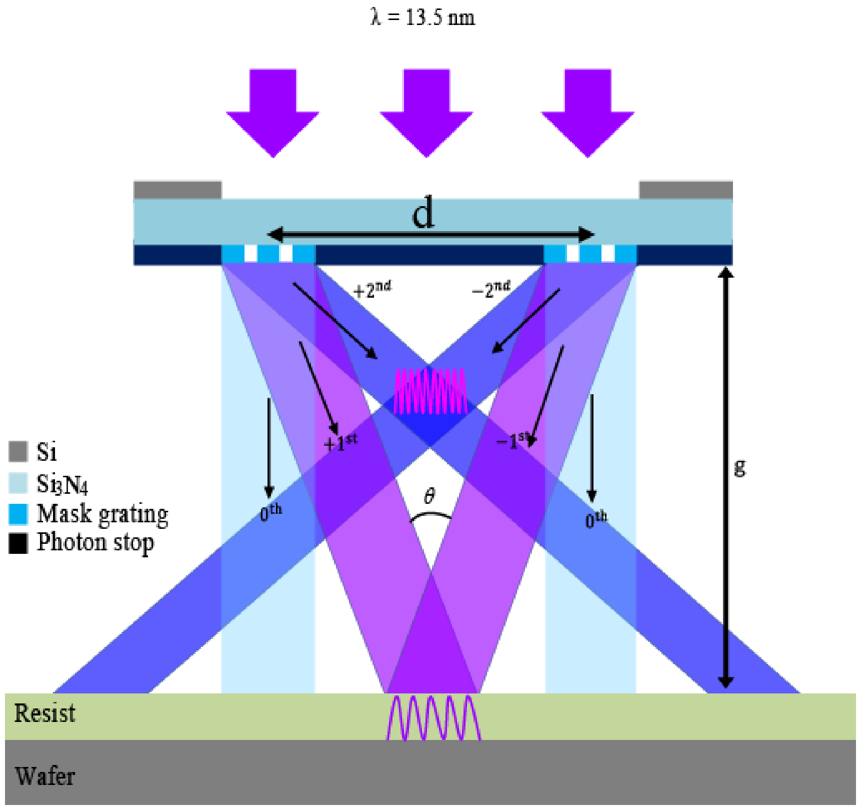
EUV Interference lithography



X. Wang,. et al J. Micro/Nanolith. MEMS MOEMS 18(1), 013501 (2019)

N. Mojarad,. et al Nanoscale 7, 4031-4037 (2015)

EUV Interference lithography



$$\sin(\theta/2) = m\lambda/P \qquad p_I = \frac{\lambda}{2\sin(\theta/2)} = \frac{P}{2m}$$

P : grating period

m : diffraction order

→ m=1, 1^{st} order, p_I=P/2

→ m=2 : 2^{nd} order, p_I=P/4

To achieve high resolution: beyond hp 10 nm, hp 8 nm for high-NA, due to the high aspect ratio, 1^{st} order grating pattern collapse due to capillary force

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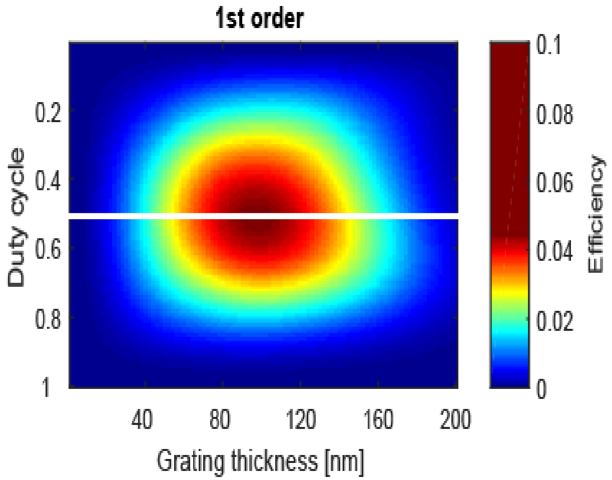
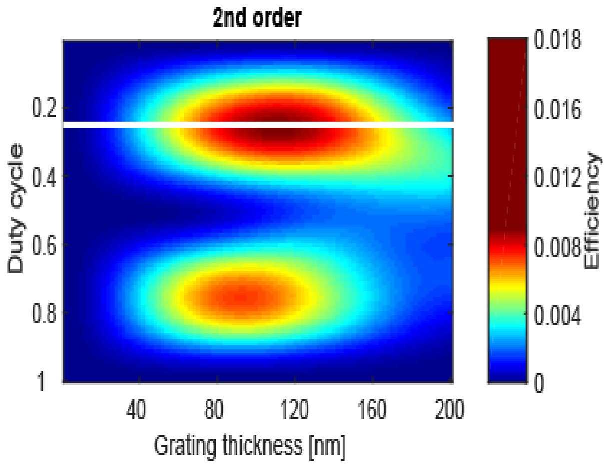
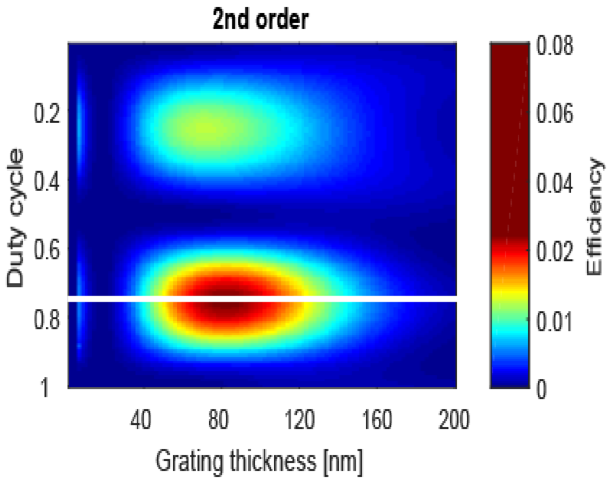
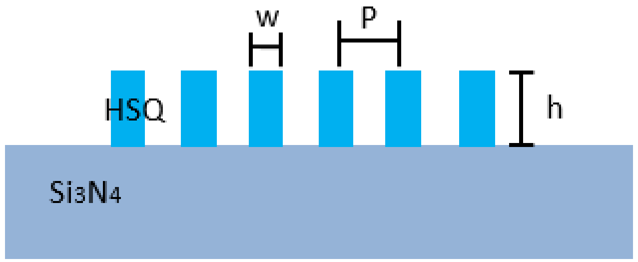
Diffraction efficiency calculation with RCWA

E.g., to obtain hp 10 nm line/space on wafer: two ways (1) first order interference, P = 40 nm; (2) second order P = 80 nm







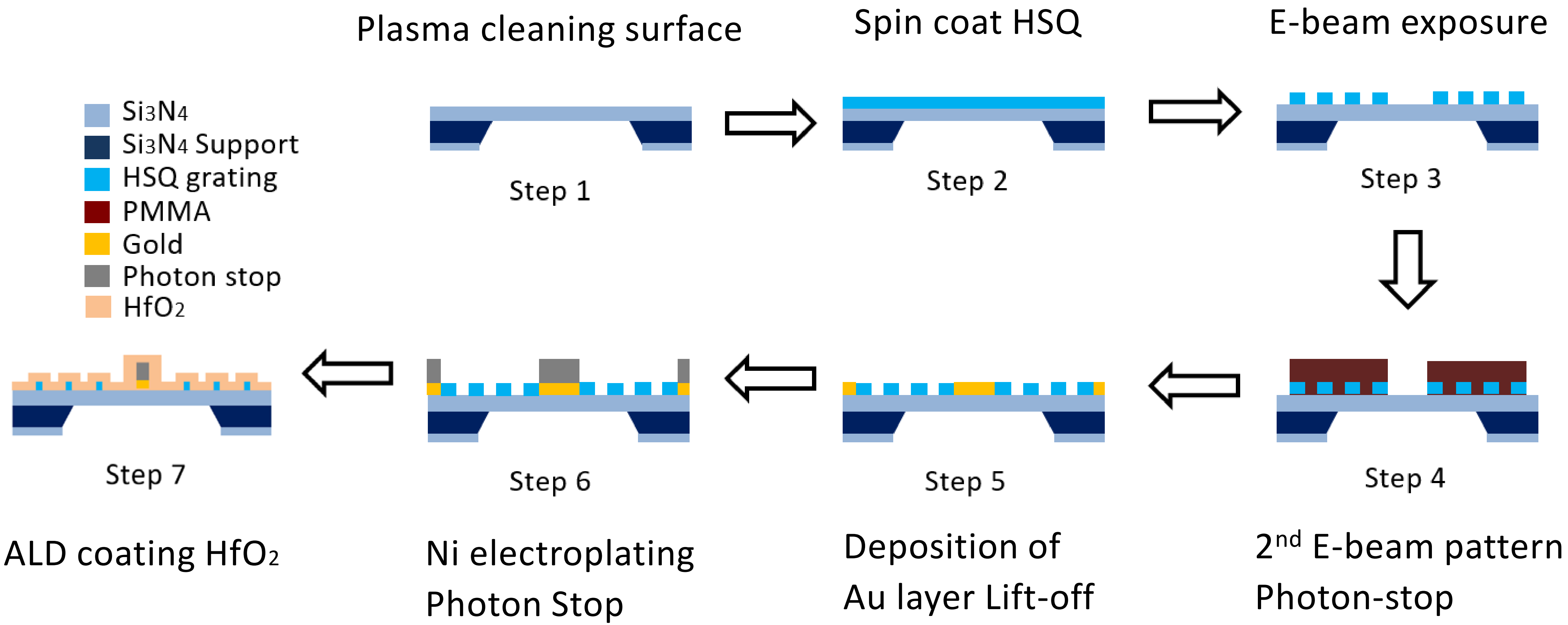


Line: space – 1:1

Line: space – 1:3

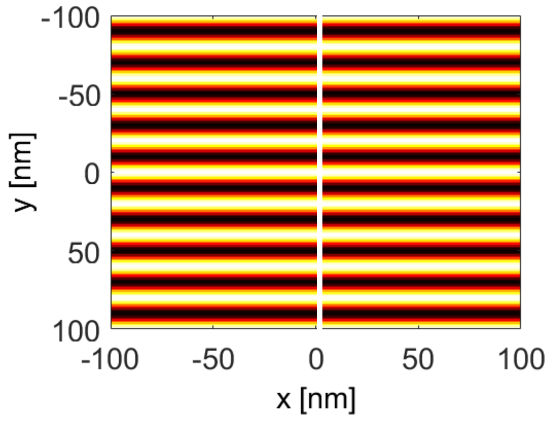
Line: space – 3:1

Diffraction Grating Masks Fabrication

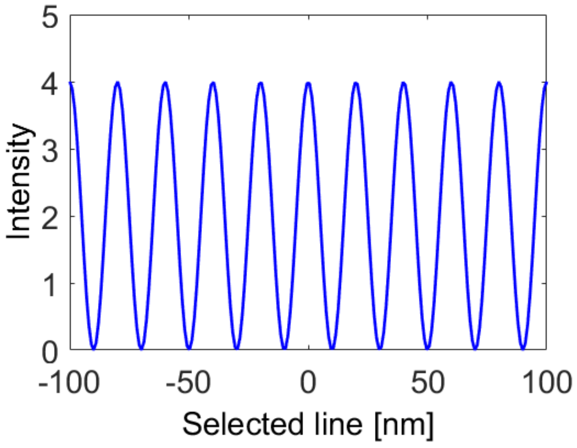


Why EUV-IL?

- High resolution: – theoretical limit = HP 3.5 nm – limited by material at this moment
- Well-defined aerial image: (1) aberration free, (2) no depth of focus, (3) pitch independent contrast = 1, NILS = π



Cross section



$$V = \frac{I_{max} - I_{min}}{I_{max} + I_{min}} = 1$$

- Flexibility: accepting contaminating and out-gassing resists, amount of materials
- Low-cost for industrial users and cost-free for academic users

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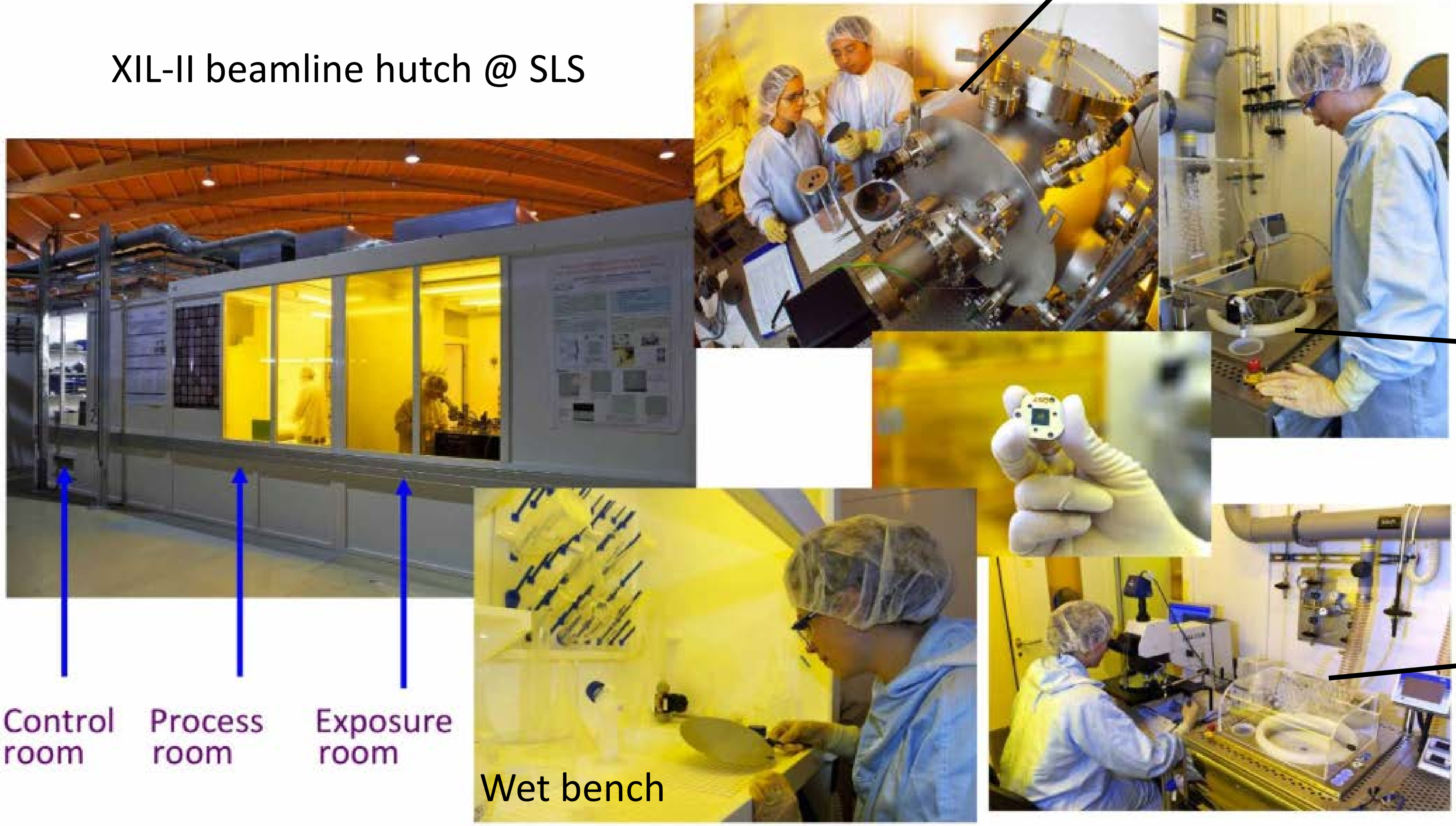
EUV-IL and Resist Testing at PSI



On-site cleanroom for pre- and post-processing of wafers

Resist Screening Program

Aims:

- Resist screening for HP 16 nm, HP 14 nm and beyond
- Support EUV resist development
- Understanding the insight of the principle of EUV resist exposure: e.g., impact of different processing parameters on the performance

Overview last 12 months

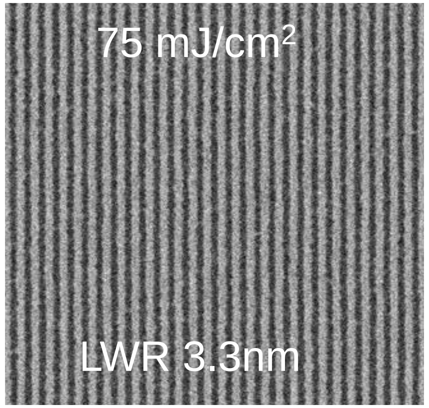
~40 different resists → 6 resist vendors → 3 resist platforms: Molecular, CAR, Inorganic → Performance of resists; PEB, Film thickness (FT)

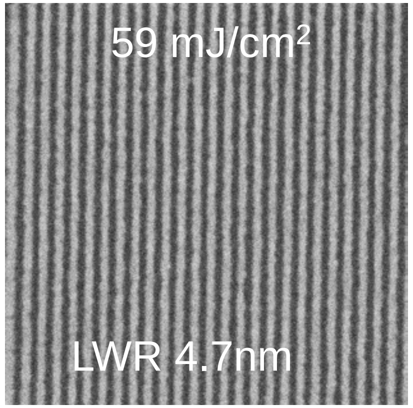
Remark: values of LWR and CD are determined for PSI tool and are not cross-calibrated with other resist testing platforms

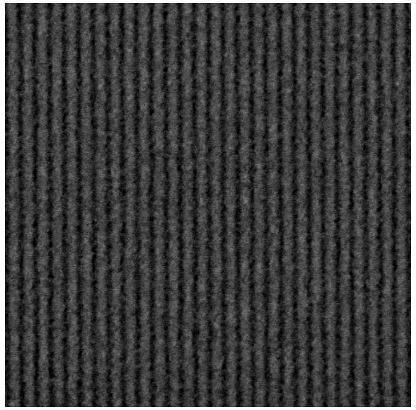
Highlights of the Resist Screening Program 2019

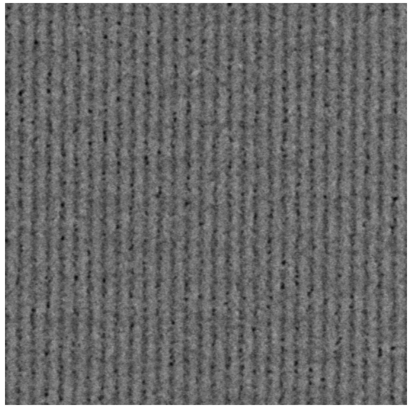
Resolution [HP] 11nm 10nm 9 nm 8 nm

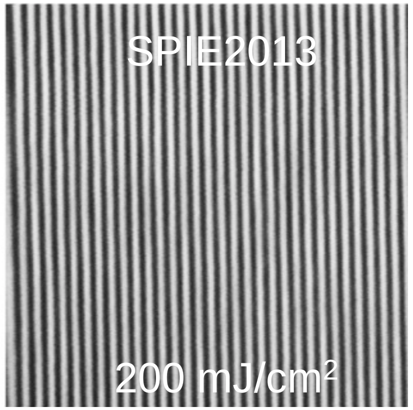
Inorganic resist



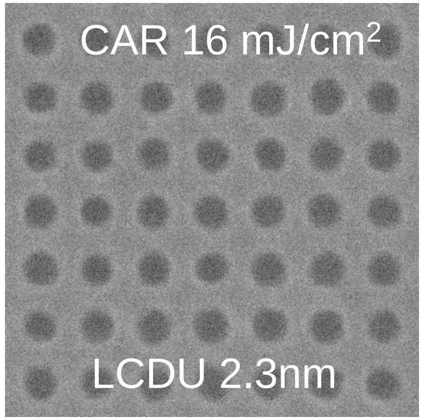


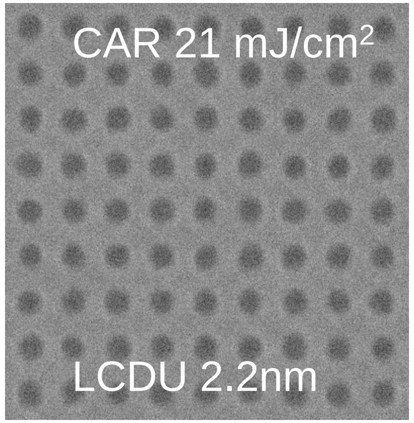


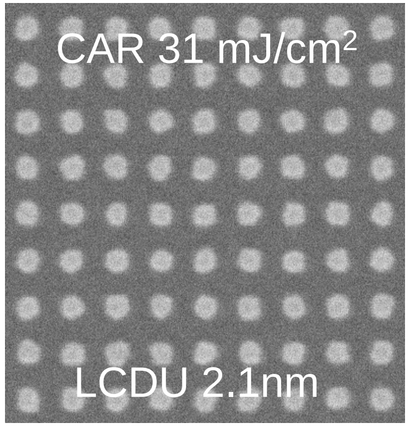


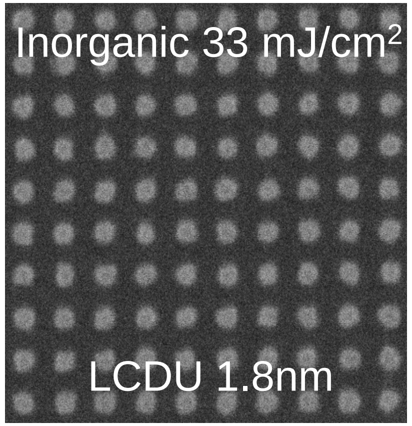


Resolution [HP] 24 nm 20 nm 20 nm 18 nm





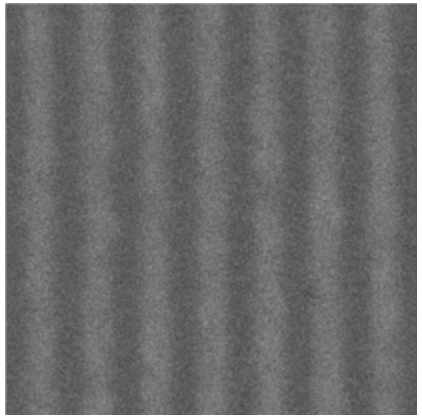




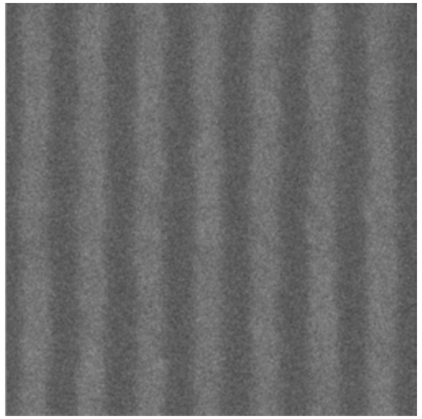
Effect of PEB temperature (hp 16nm)

Vendor 1 - molecular resist A

T1 = no PEB

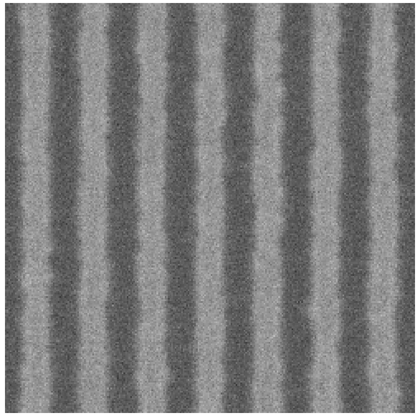


T2 = 90 °C

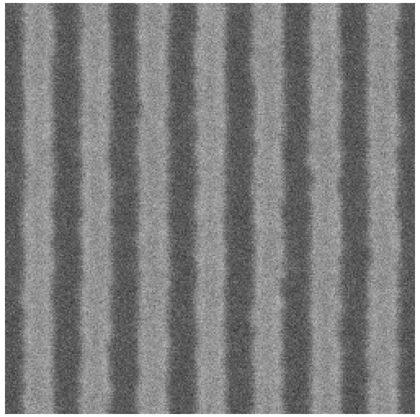


Vendor 2 - inorganic resist B

T3 = 160 °C

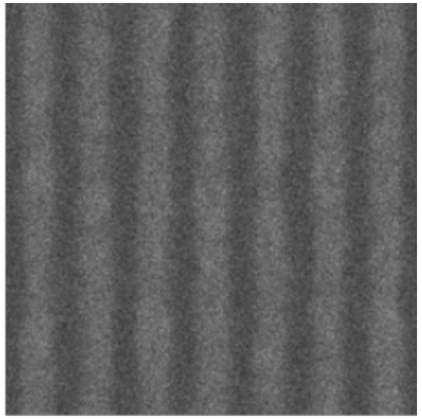


T4 = 170 °C

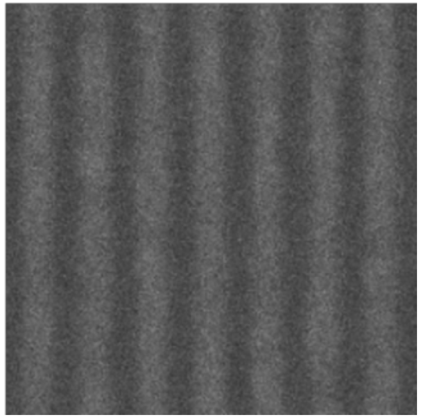


Vendor 3 - CAR C

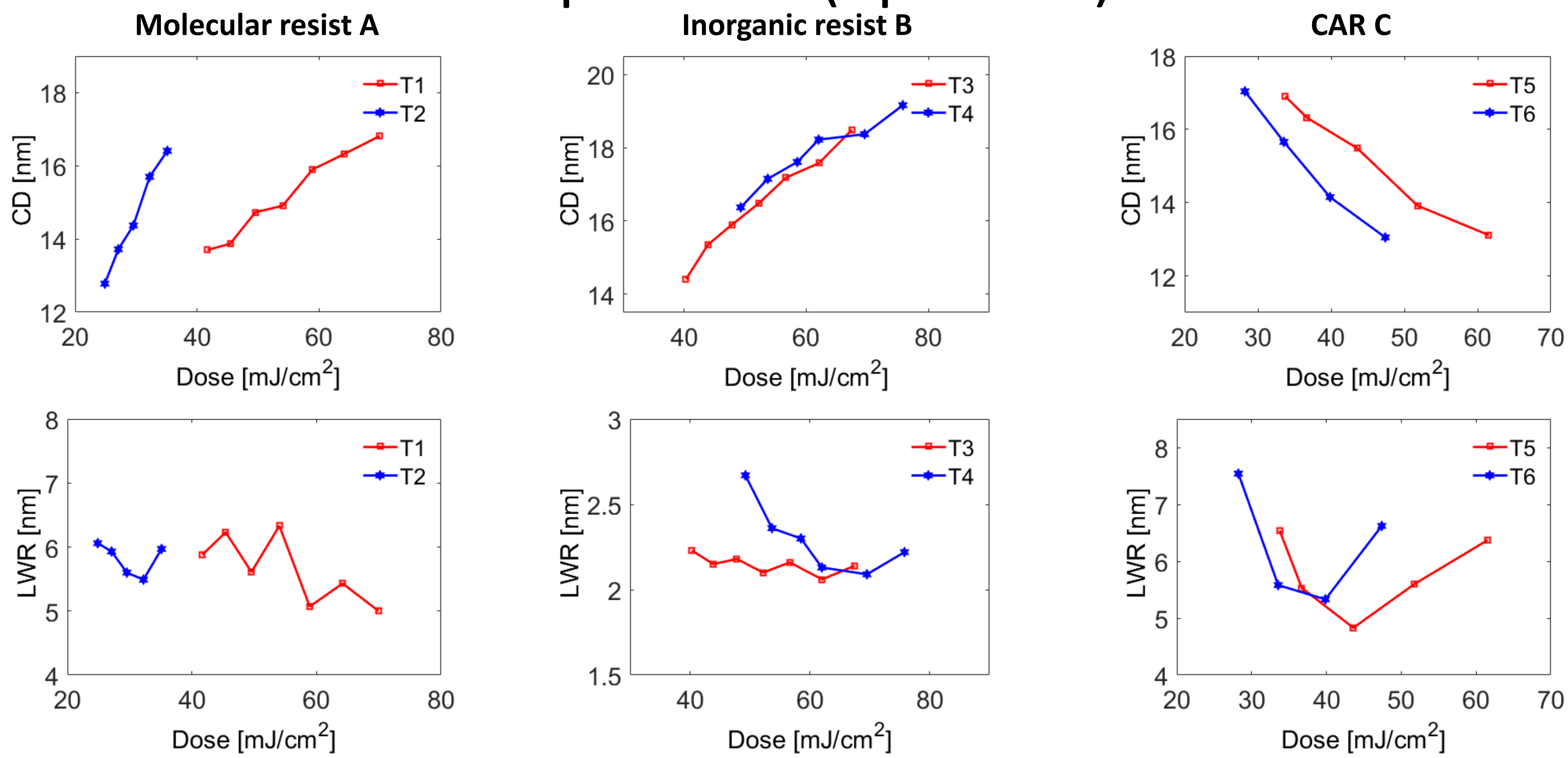
T5 = 60 °C



T6 = 70 °C



Effect of PEB temperature (hp 16nm) on dose and LWR



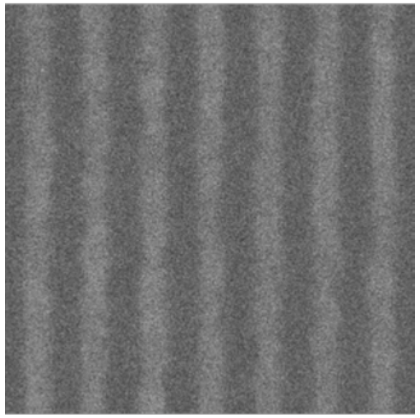
Vendor	Resist	Temperature (°C)	Dose (mJ/cm^2)	LWR (nm)
Vendor 1	Molecular A	T1 = no baking	62	4.9
		T2 = 90 °C	34	5.3
Vendor 2	Inorganic B	T3 = 160 °C	52	2.5
		T4 = 170 °C	45	2.6
Vendor 3	CAR C	T5 = 60 °C	39	7.8
		T6 = 70 °C	31	7.9

Remark: 2 times more dose for molecular resist without PEB; LWR are not getting much worse

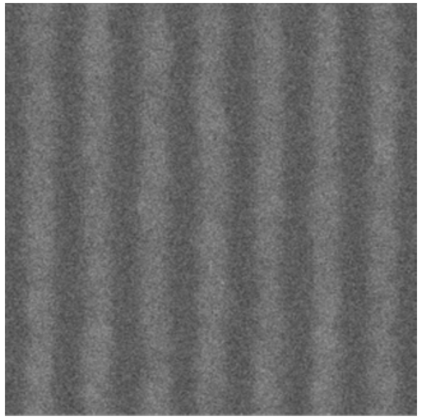
Effect of FT (hp 16nm)

Vendor 4 - molecular resist D

H1 = 23 nm

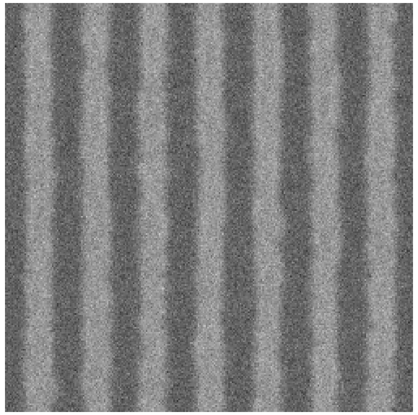


H2 = 20 nm

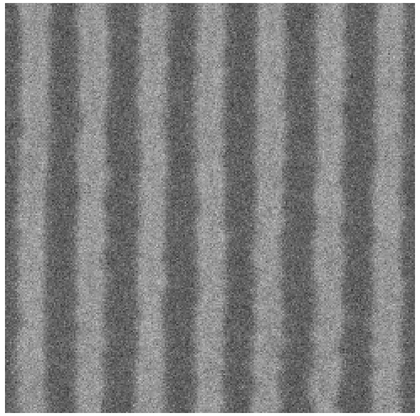


Vendor 5 - inorganic resist E

H3 = 18 nm

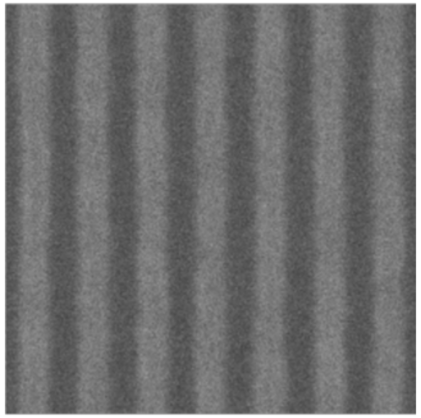


H4 = 16 nm

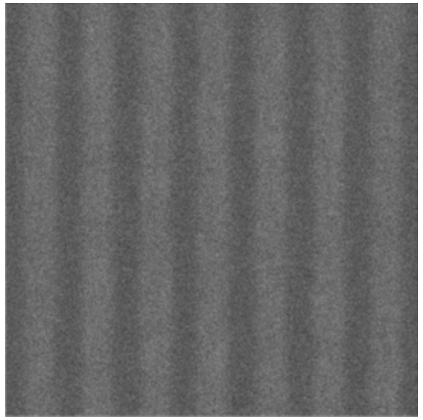


Vendor 6 - CAR F

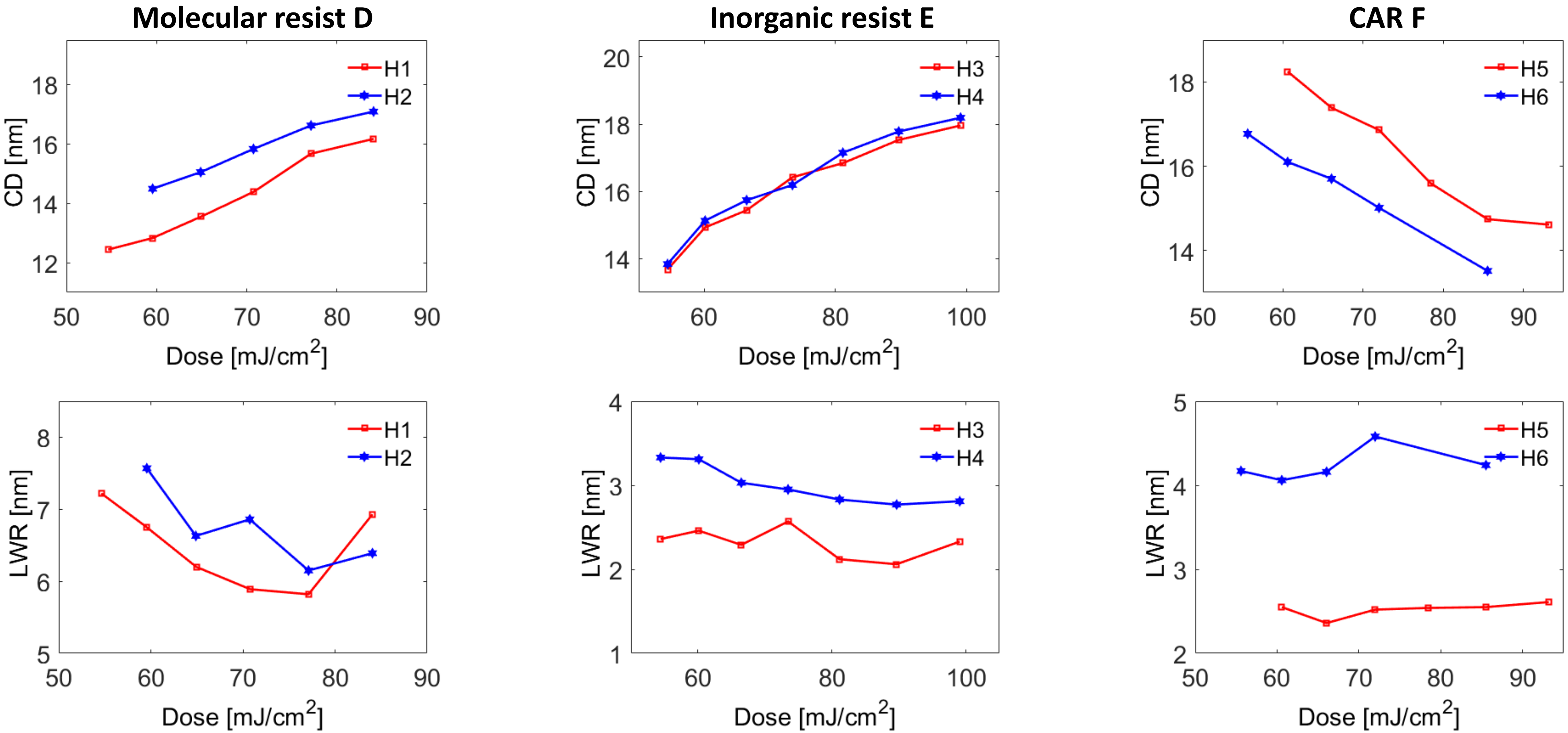
H5 = 29 nm



H6 = 19 nm



Effect of FT (hp 16nm) on dose and LWR



Vendor	Resist	Thickness (nm)	Dose (mJ/cm^2)	LWR (nm)
Vendor 4	Molecular D	H1 = 23 nm	64	5.6
		H2 = 20 nm	54	5.8
Vendor 5	Inorganic E	H3 = 18 nm	95	3.4
		H4 = 16 nm	91	4.0
Vendor 6	CAR F	H5 = 29 nm	76	2.6
		H6 = 19 nm	61	5.6

Remark: 10 nm FT more increase LWR 2 times more for CAR

Conclusions and Outlook

Conclusions

- EUV-IL is an effective tool for resist evaluation
- Record resolution: CAR-hp 12 nm and Inorganic resist hp 9 nm (8nm for old inorganic resist)
- PEB: higher PEB-lower dose-higher LWR; particularly for molecular resist 2 times more dose required without PEB
- FT: RLS trade off – thinner FT- lower dose-higher LWR

Outlook

- We will furtherly optimize processing parameters in order to push the resolution
- We will continue monitoring EUV resists for current and future technology nodes
- We hope to see more resist progress and we are looking forward to working with more resist vendors

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Thank you for your attention!

http://www.psi.ch/sls/xil

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Wir schaffen Wissen – heute für morgen