IRRESISTIBLE MATERIALS

EUV Lithography using Multi-Trigger Resist

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UNIVERSITY OF BIRMINGHAM

nano-c nanostructured carbon

EMD PERFORMANCE MATERIALS

Talk Summary

- Introduction
- Lines and Spaces
  - Overview of prior standard activation energy / standard opacity
  - Varying activation Energy and Opacity
- Pillars
  - Low Activation Energy – standard and high opacity
  - High Activation Energy – high opacity
- Conclusions

IRRESISTIBLE MATERIALS

Overview

- Traditionally, lithography has focussed on improving resolution year on year
  - Width of the lines (etc) decreases
  - Roughness has to be below a certain level for device performance
  - Sensitivity has to be economically viable for throughput
- With EUV lithography and the paucity of EUV photons this is still the goal, but the headache at higher resolution is:

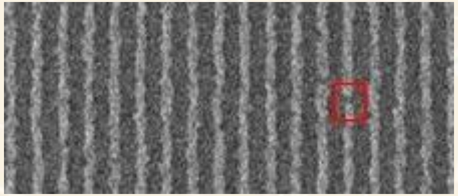
STOCHASTICS

leads to

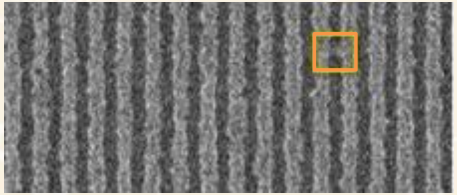
LITHOGRAPHIC DEFECTS

We are addressing material stochastics through reduction in the number of resist components, targeting a single-component monodisperse resist material as the ultimate goal.

We are addressing photon stochastics via the introduction of the multi-trigger effect, which suppresses the photon shot noise/increases edge contrast via an inherent dose dependent quenching, and secondly via the increase of opacity.



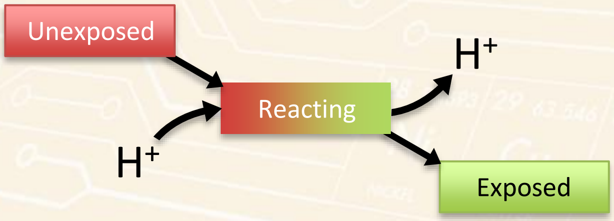
Line breaks



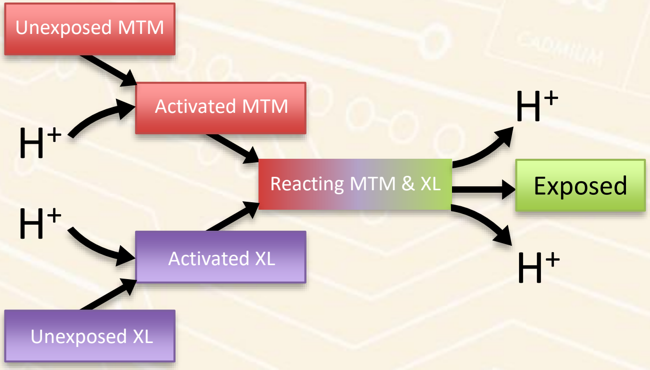
Microbridging

Multi Trigger

CAR



MTR



MULTI-TRIGGER MECHANISM

1. Photons produce Initiators (e.g. PAG acid)
2. Initiators activate resist molecules

3a. If two activated molecules are adjacent they react (resist exposure)
AND
Both initiators are released

3b. If an activated molecule is not close to a second activated molecule the initiator remains bound and there is no exposure event.

Self limiting reaction - **Gives better edge definition**

Unexposed MTM has a protected crosslinkable functional group

- Can not crosslink when protected
- If protonated will deprotect (and regenerate proton) in presence of a nucleophile

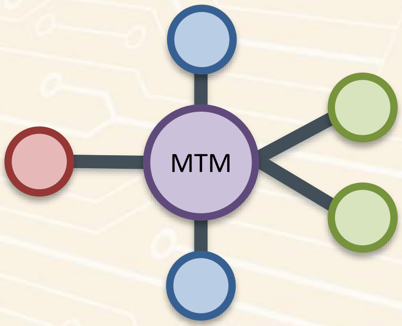
Unexposed XL has proton activated crosslinking functional group

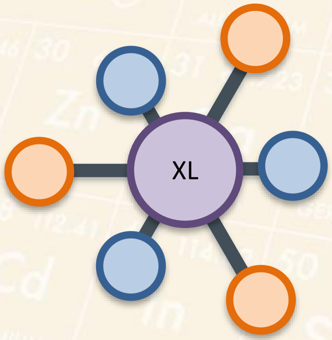
- Can self-crosslink, or crosslink with deprotected molecule A (regenerating two protons in second case)
- Electrophilic. Becomes nucleophilic if protonated.

IRRESISTIBLE MATERIALS

Molecule Development - MTR

The two main components of the MTR resist comprise the MTM molecule and the Crosslinker





Current work is focusing on:

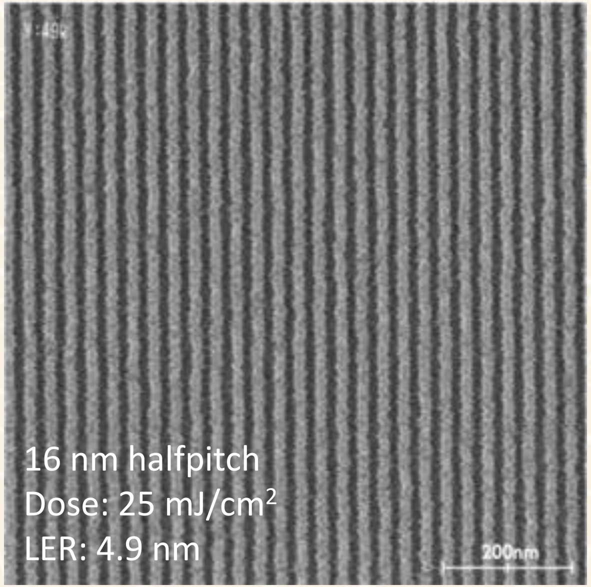
- Choice of high opacity groups, and
- Activation of the labile protecting groups

Standard Activation Energy and Opacity

The self-quenching concept has been demonstrated in NXE3300 at imec

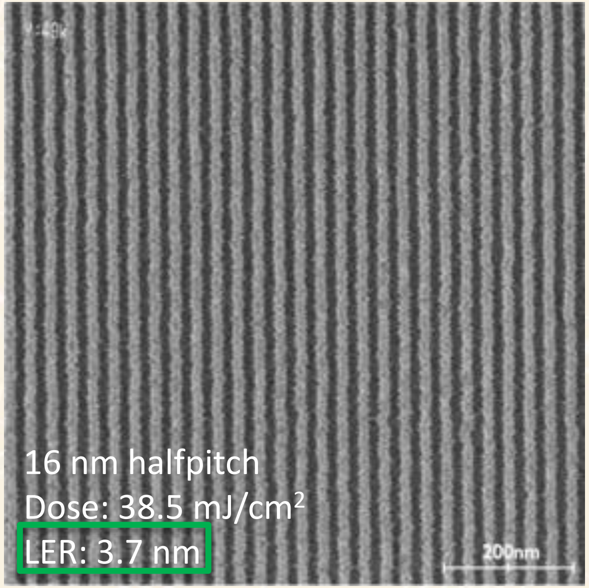
MTR2200

Formulated for weak MTR effect



MTR2204

Formulated for strong MTR effect



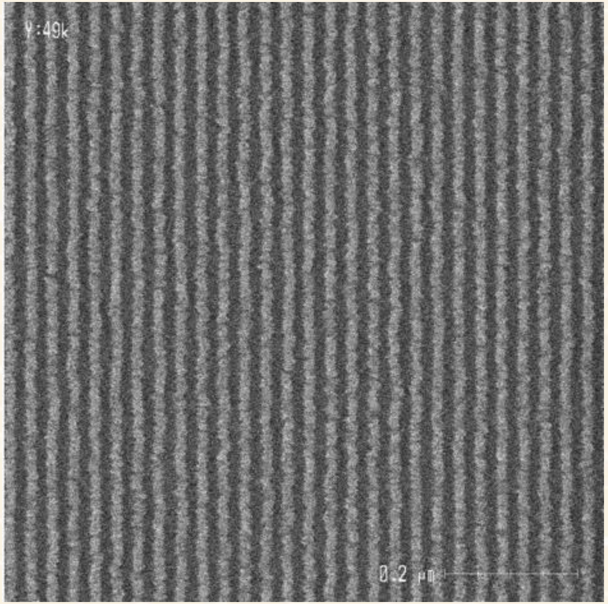
Imec. Unbiased LER

The MTR system is ultimately designed to enable the whole film to act as a dose dependent quenching system – eliminating quencher stochastics

Y. Vesters, SPIE 2018, 10583

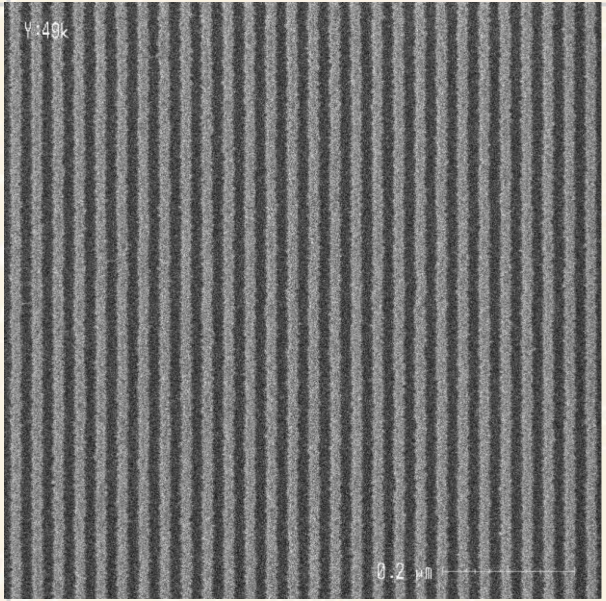
Low Activation Energy Protecting Group

MTR4204-1



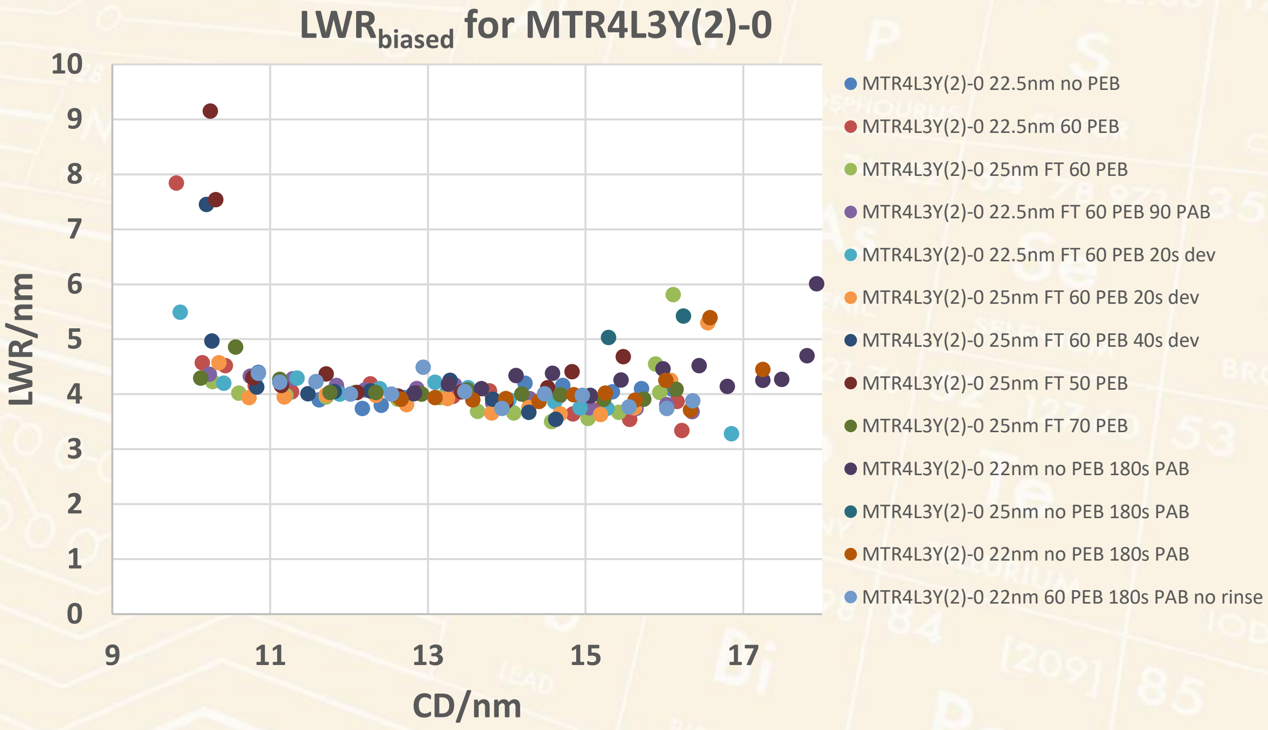
FT 30nm
PEB None
Dev nBA 30s
Rinse nBA 15s
CD 14.8nm
Dose 51mJ/cm^2
LWR -

MTR4L3Y(2)-0



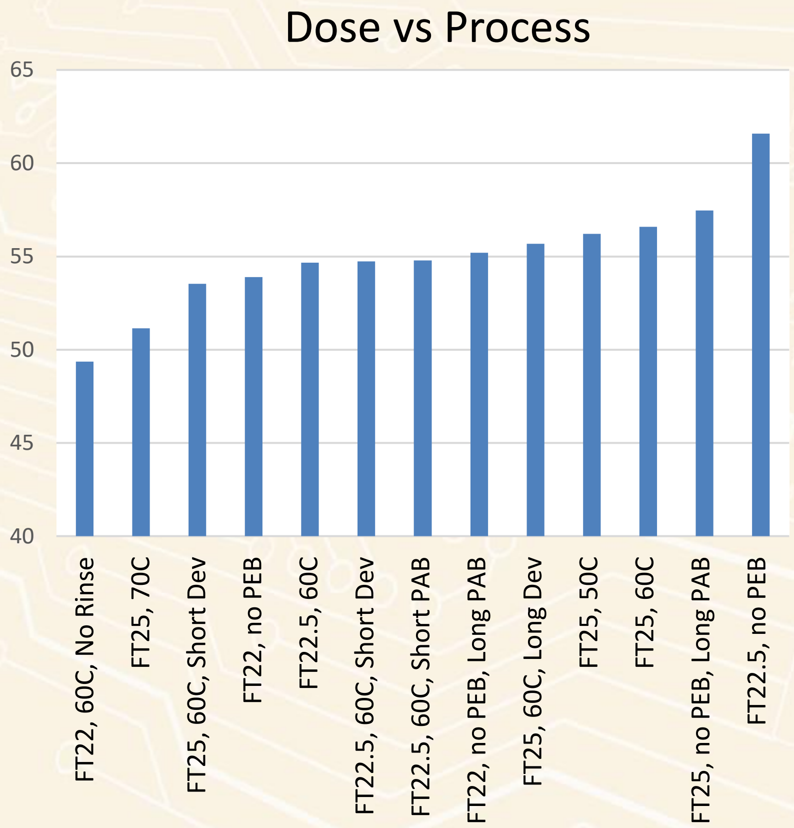
FT 22.5nm
PEB None
Dev nBA 30s
Rinse nBA 15s
CD 15.07nm
Dose 51mJ/cm^2
LWR 4.22 nm (Biased)

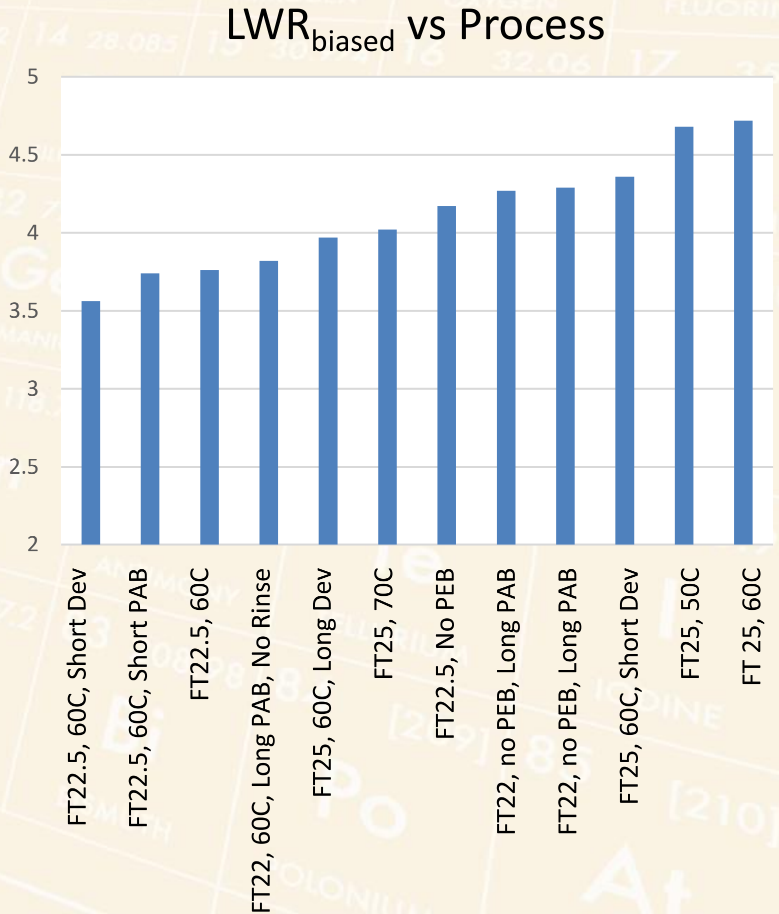
MTR4L3Y(2)-0 – Process Variations



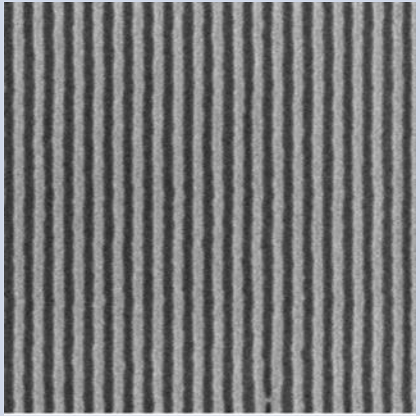
On the macro level, the LWR is remarkably level from 11nm to 15nm line width

MTR4L3Y(2)-0 – Process Variations





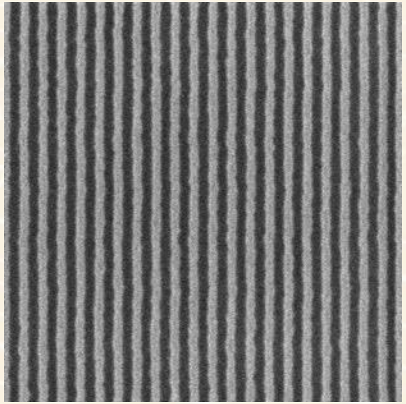
Example MTR4L3Y(2)-0 Images: Development time for 22.5nm FT

22.5 nm FT 60C PEB	W12 21.3	W8 21.3
Development time	20s dev	30s dev
Dose to size (mJ/cm^2)	54.7	54.7
LWR at DtS (nm)	3.56	3.76
Image details Dose (mJ/cm^2) CD (nm) LWR (nm)	 51 15.63 3.68	 52.5 15.56 3.54
Image		

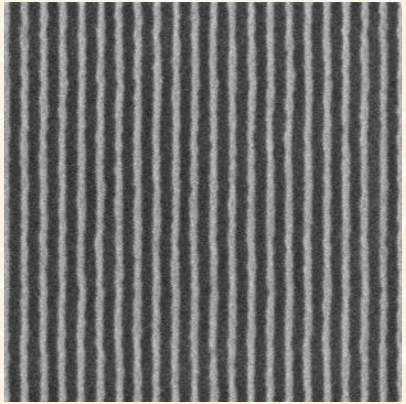
- Dose does not change with development time with this FT and PEB temp
- LWR at DtS is 0.2nm less with 20 sec development compared to 30s

MTR4L3Y(2)-0 Sparse Line Performance

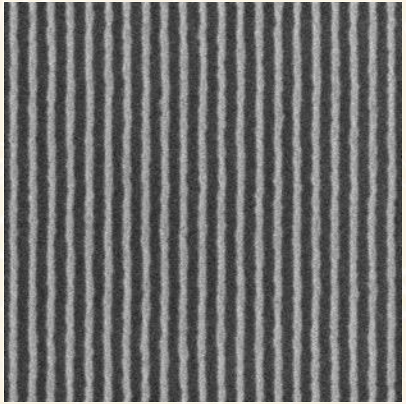
W10, CD 14.67, LWR 3.92, Dose 49.5



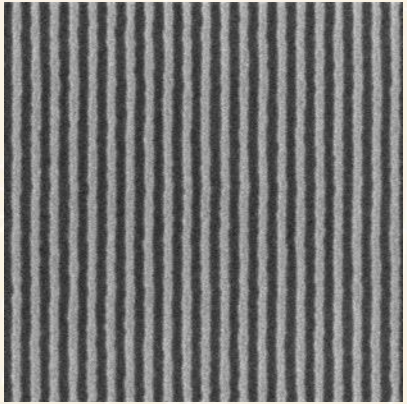
W10, CD 11.38, LWR 4.21, Dose 39



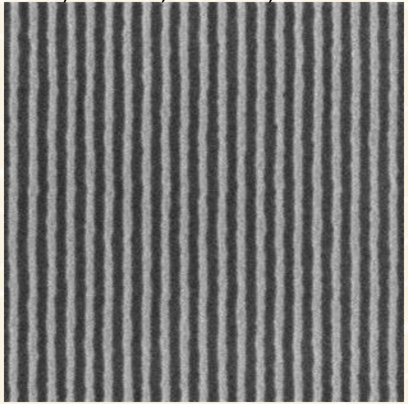
W12, CD 11.88, LWR 4.00, Dose 40.5



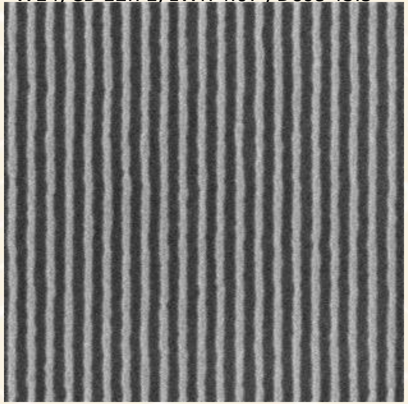
W12, CD 14.35, LWR 3.78, Dose 48



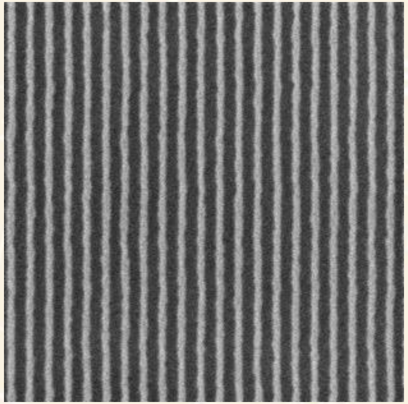
W14, CD 13.39, LWR 4.11 , Dose 45



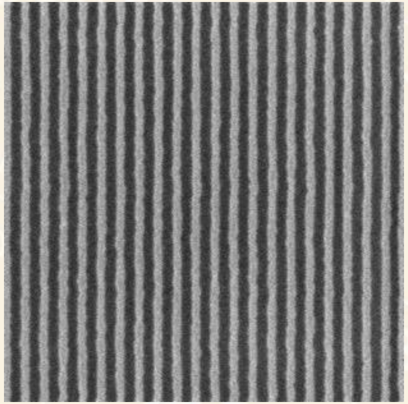
W14, CD 12.71, LWR 4.07 , Dose 43.5



W13, CD 11.3, LWR 4.02, Dose 39



W13, CD 13.81, LWR 3.66, Dose 46.5

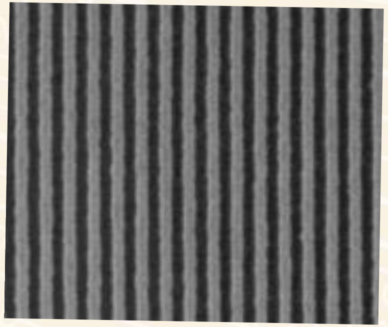


Exposures undertaken by

SMILE data

MTR4L3Y(2) data at PSI

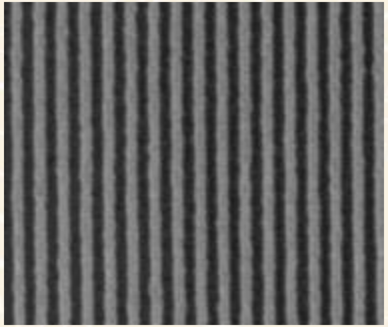
p32



Dose: 66.2mJ/cm^2
CD: 16.01nm
LWR: 1.59nm

FT 25nm
60C PEB

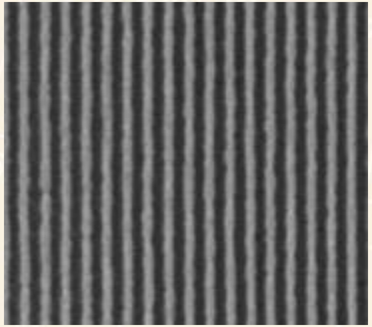
p30



Dose: 51.8mJ/cm^2
CD: 14.99nm
LWR: 1.75nm

FT 25nm
60C PEB

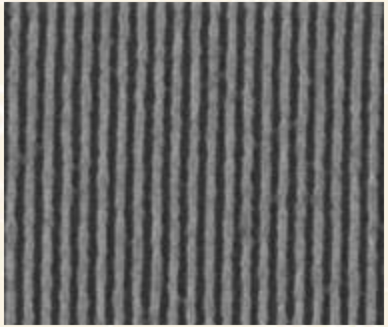
p28



Dose: 37.2mJ/cm^2
CD: 12.2nm
LWR: 2.07nm

FT 25nm
60C PEB

p26

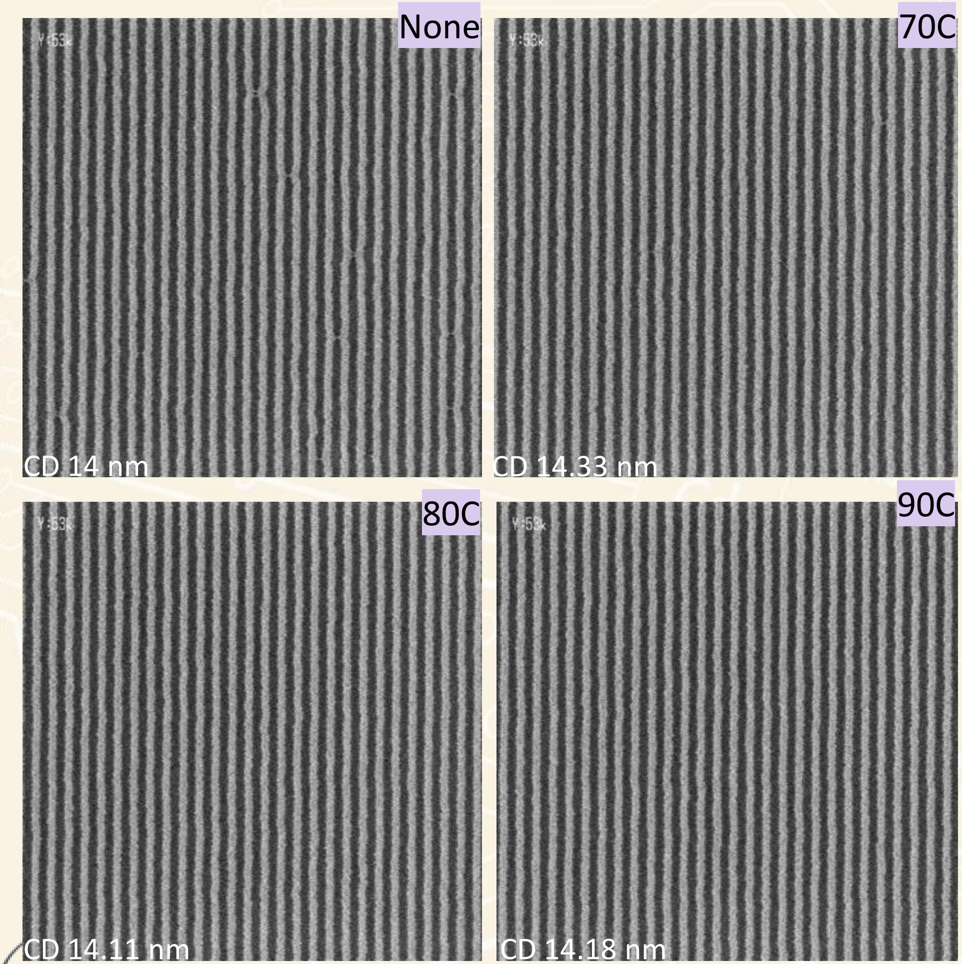


Dose: 37.2mJ/cm^2
CD: 13.2nm
LWR: 2.58nm

FT 18nm
No PEB

MTR8L3Y(2)-0, 32p FT 22nm

PEB variation



PEB T	DtS	LWR_{biased}@ HP	LER_{biased}@ HP	EL%
None	51.76	3.67	3.45	22.01
70	51.33	4.02	3.47	21.09
80	45.90	3.89	3.26	18.57
90	44.16	3.85	3.19	18.71

MTR8L3Y(2)-0 is slightly faster than MTR4L3Y(2)-0

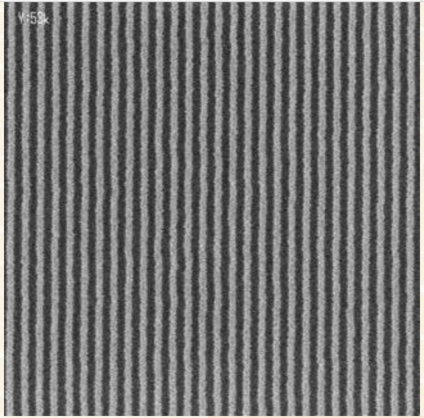
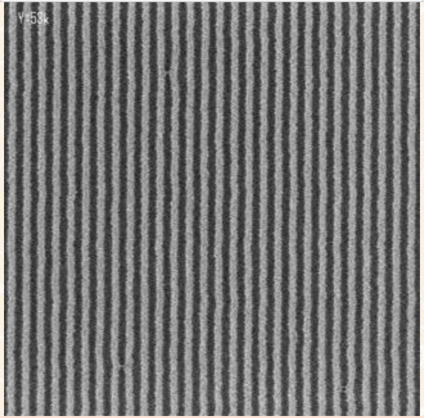
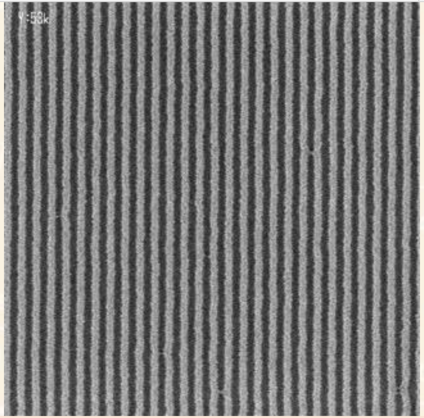
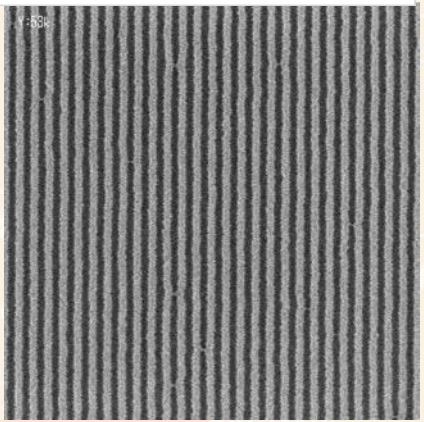
Sensitivity increases with PEB

LWR increases @70C but starts decreasing with higher PEB.

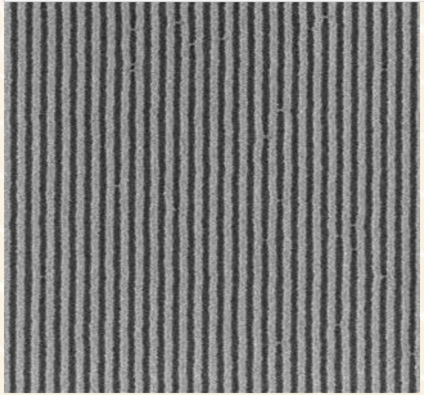
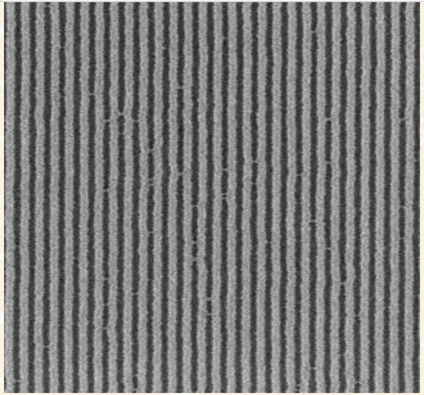
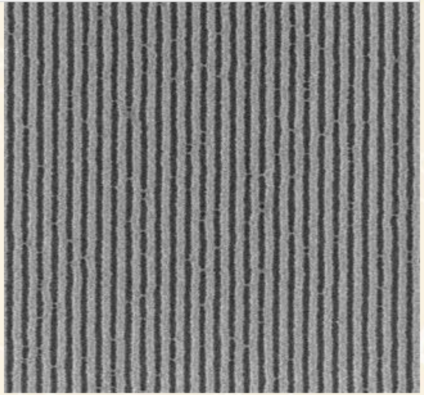
- LER is lowest @90C
- Not a significant difference btw 80 and 90

MTR8L3Y(2)-0 90°C PEB

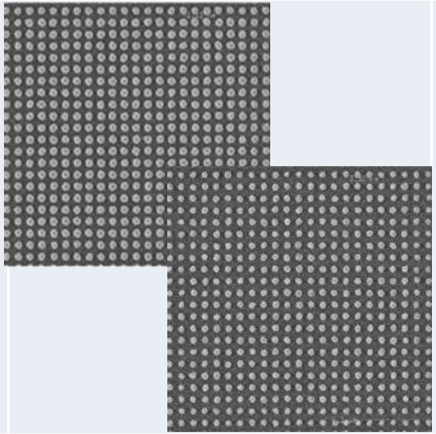
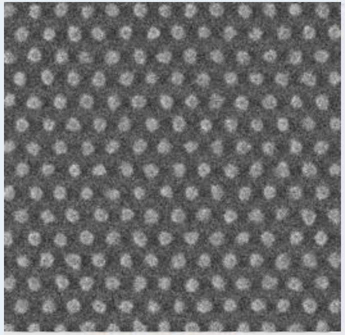
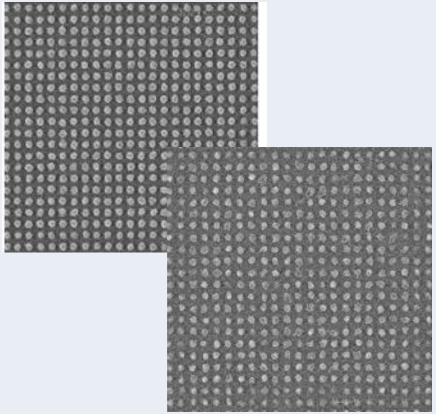
39.5	41	42.5	44
14.18	14.8	15.41	16.05
3.85	3.9	3.85	3.86

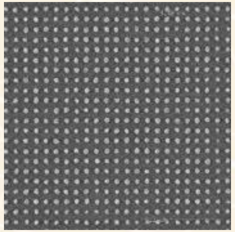
45.5	47	48.5
16.66	17.26	17.91
3.86	4	4.09

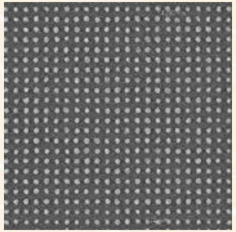




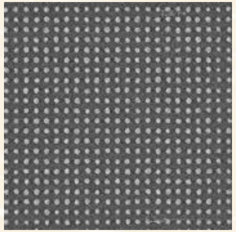
Pillars

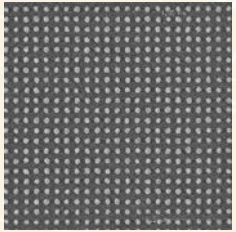
p40	MTR8L3Y(2)-0	MTR4L3Y(2)-0	MTR4204-1
Process conditions	FT 25nm No PEB 30s nBA dev MIBC rinse Reticle CD = 25nm? (checking)	FT 22.5nm No PEB 30s nBA dev 15s NBA rinse Reticle CD = 24nm	FT 25nm No PEB nBA dev No rinse Reticle CD = 25nm? (checking)
Dose	72 mJ/cm^2 for CD = 23.68nm 60mJ/cm^2 for CD = 20.04nm	~70mJ/cm^2 for CD = 25nm 57.9mJ/cm^2 for CD = 20nm	64.5 mJ/cm^2 for CD = 24.21nm 45mJ/cm^2 for CD = 20.79nm
LCDU	2.63 for CD = 23.68nm 3.38 for CD = 20.04nm	3.4 for CD = 25nm 3.9 for CD = 20nm	3.32 for CD = 24.21nm 6.96 for CD = 20.79nm
		 Reticle CD 24nm	

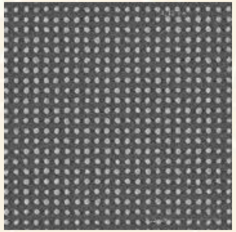
P40 pillars: MTR8L3Y(2)-0 images with increasing dose (for focus -0.07)

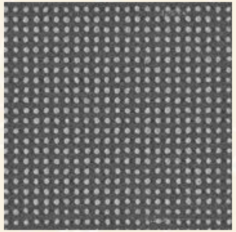

Dose 46 mJ/cm^2
CD: 16.57 nm
CDU: 4.49 nm

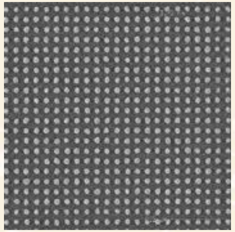

Dose 48 mJ/cm^2
CD: 17.30 nm
CDU: 4.50 nm

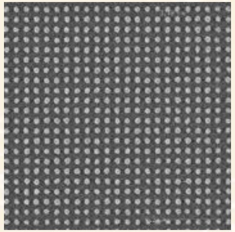

Dose 50 mJ/cm^2
CD: 17.84 nm
CDU: 3.86 nm

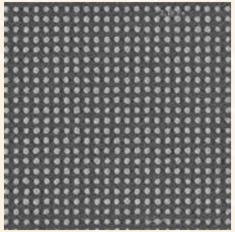

Dose 52 mJ/cm^2
CD: 18.38 nm
CDU: 4.05 nm

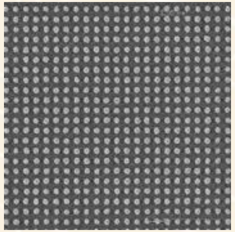

Dose 54 mJ/cm^2
CD: 18.77 nm
CDU: 4.12 nm

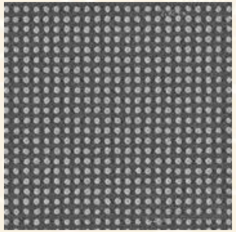

Dose 56 mJ/cm^2
CD: 19.36 nm
CDU: 3.78 nm

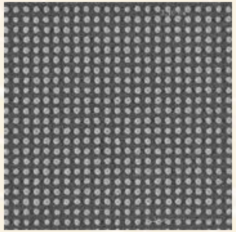

Dose 58 mJ/cm^2
CD: 19.55 nm
CDU: 3.72 nm

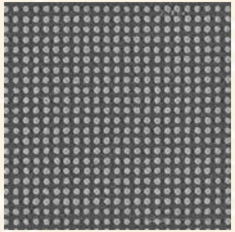

Dose 60 mJ/cm^2
CD: 20.22 nm
CDU: 3.49 nm

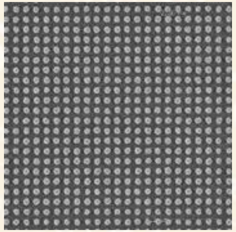

Dose 62 mJ/cm^2
CD: 20.81 nm
CDU: 3.19 nm

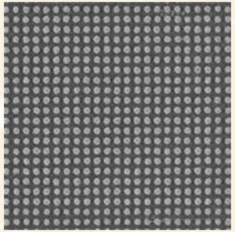

Dose 64 mJ/cm^2
CD: 21.45 nm
CDU: 3.05 nm

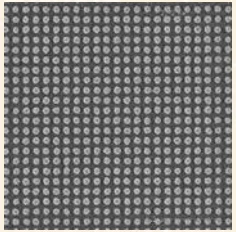

Dose 66 mJ/cm^2
CD: 22.13 nm
CDU: 2.92 nm


Dose 68 mJ/cm^2
CD: 22.65 nm
CDU: 3.10 nm


Dose 70 mJ/cm^2
CD: 23.23 nm
CDU: 2.74 nm


Dose 72 mJ/cm^2
CD: 23.65 nm
CDU: 2.86 nm


Dose 74 mJ/cm^2
CD: 24.59 nm
CDU: 2.76 nm


Dose 76 mJ/cm^2
CD: 25.34 nm
CDU: 2.72 nm

PSI Update – High Opacity Crosslinker

- Hands off screening by ASML.

- Three formulations:
  - MTR2Z(T)0Y(E)-0
    - Model optimised for lowest LWR
  - MTR2Z(T)0Y(F)-0
    - Model optimised for lowest Z factor
  - MTR2L1Y(G)-0
    - Model optimised for sensitivity (whilst keeping other factors within ‘desirability’ limits)

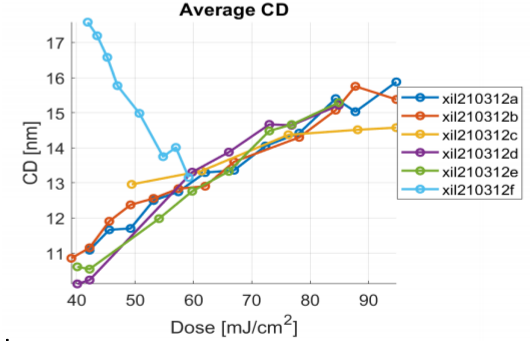
IRRESISTIBLE MATERIALS

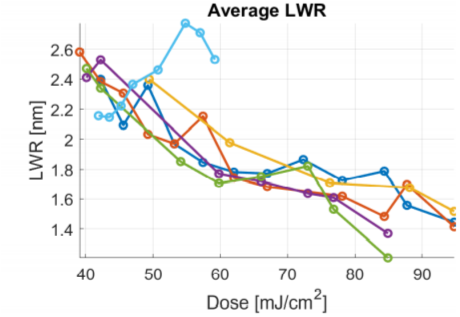
Exposures undertaken by ASML PAUL SCHERRER INSTITUT PSI

p32

PAUL SCHERRER INSTITUT PSI

Pitch: 32 nm



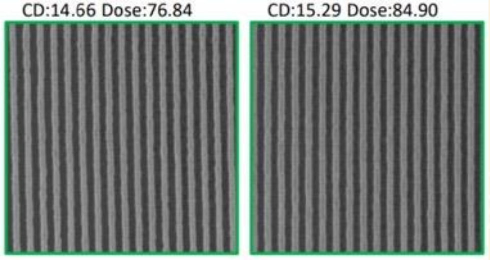


SMILE data

Exposure	Description	Dose_to_size	Rel_Dose	EL (%)	EL_Act (%)	CD_Sens	LWR_unbias	LWR_min
xil210312a	MTR2Z(T)0Y(E)	94.41	1.99	37.21	> 55.66	0.09	1.44	1.44
xil210312b	MTR2Z(T)1Y(F)	95.12	2.01	38.00	> 55.25	0.08	1.70	1.41
xil210312c	MTR2L1Y(G) + PEB	123.25	2.60	62.53	36.78	0.05	1.52	1.52
xil210312d	MTR2Z(T)0Y(E) + PEB	85.52	1.80	28.99	> 29.36	0.11	1.37	1.37
xil210312e	MTR2Z(T)1Y(F) + PEB	88.93	1.88	31.66	> 34.62	0.10	1.21	1.21
xil210312f	Beamline-reference	47.39	1.00	26.31	31.86	0.12	2.36	2.15

All resists resolved p32, at high doses; LWR$_{unb}$ values are low (1.2-1.7nm), especially w/ PEB

MTR2Z(T)1Y(F) + PEB



LWR = 1.53nm LWR = 1.21nm

- PEB reduced dose by 7-10%
- LWR improved with PEB
- Best LWR at p32 = 1.21nm
  - Z factor = 5.33e-9

MTR4L3Y(2)-0 with PEB Nov test:

- *LWR = 1.61nm*
- *Dose = 65.6mJ/cm^2*
- *Z factor 6.99e-9*

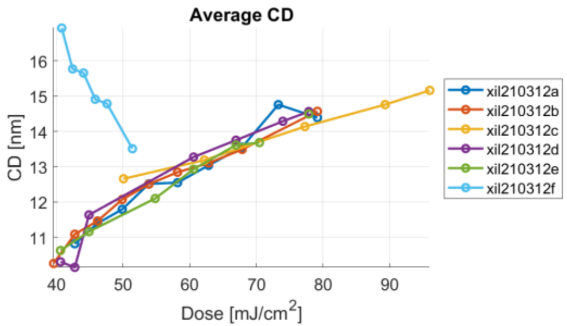
IRRESISTIBLE MATERIALS

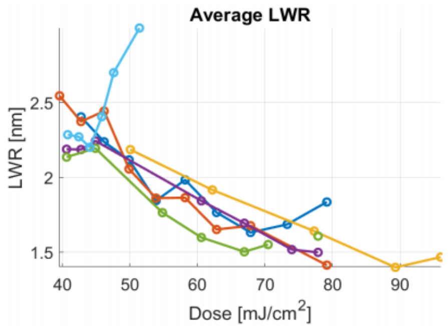
Exposures undertaken by ASML PAUL SCHERRER INSTITUT PSI

p30

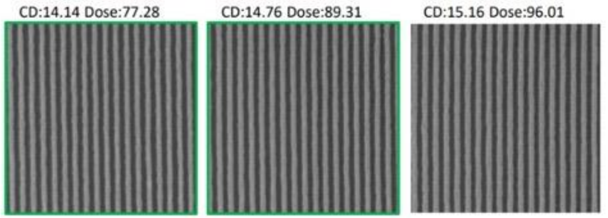
PAUL SCHERRER INSTITUT PSI

Pitch: 30 nm





MTR2Z(T)1Y(G) + PEB



LWR = 1.64nm LWR = 1.40nm LWR = 1.47nm

SMILE data

Exposure	Description	Dose_to_size	Rel_Dose	EL (%)	EL_Act (%)	CD_Sens	LWR_unbias	LWR_min
xil210312a	MTR2Z(T)0Y(E)	80.38	1.74	34.72	41.02	0.09	1.69	1.63
xil210312b	MTR2Z(T)1Y(F)	82.34	1.78	37.94	44.19	0.08	**1.41**	1.41
xil210312c	MTR2L1Y(G) + PEB	93.35	2.02	57.88	42.02	0.05	**1.47**	1.40
xil210312d	MTR2Z(T)0Y(E) + PEB	78.34	1.69	31.65	44.79	0.09	**1.50**	1.50
xil210312e	MTR2Z(T)1Y(F) + PEB	81.64	1.77	34.80	31.31	0.09	1.61	1.50
xil210312f	Beamline-reference	46.23	1.00	21.45	11.16	0.14	2.40	2.20

All resists resolved p30, at high doses; LWR_{unb} values are low 1.4-1.7nm

- PEB reduced dose by 1-3%
- Best LWR at p30 = 1.40 nm
  - Z factor = 5.52e-9

MTR4L3Y(2)-0 with PEB Nov test:

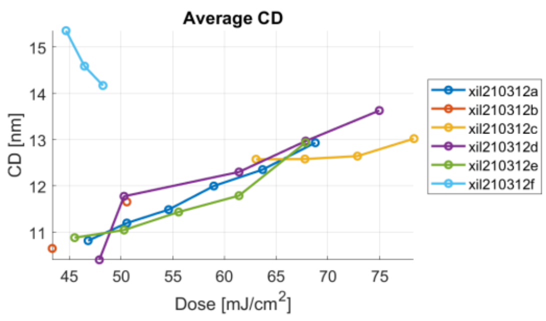
- *LWR = 1.80nm*
- *Dose = 51.7mJ/cm²*
- *Z factor 6.87e-9*

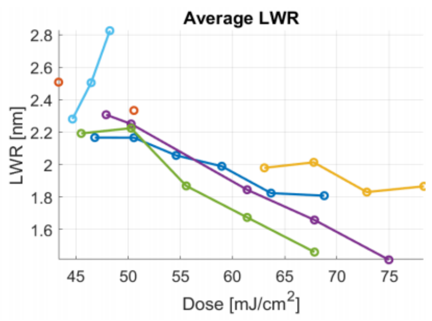
IRRESISTIBLE MATERIALS

Exposures undertaken by

p28

Pitch: 28 nm





Exposure	Description	Dose_to_size	Rel_Dose	EL (%)	EL_Act (%)	CD_Sens	LWR_unbias	LWR_min
xil210312a	MTR2Z(T)0Y(E)	80.41	1.66	36.66	16.33	0.08	1.81	1.81
xil210312b	MTR2Z(T)1Y(F)	NaN	NaN	NaN	NaN	NaN	NaN	NaN
xil210312c	MTR2L1Y(G) + PEB	105.14	2.17	71.39	4.83	0.04	1.87	1.83
xil210312d	MTR2Z(T)0Y(E) + PEB	75.43	1.55	30.49	35.90	0.09	**1.41**	1.41
xil210312e	MTR2Z(T)1Y(F) + PEB	82.12	1.69	37.09	21.38	0.08	**1.46**	1.46
xil210312f	Beamline-reference	48.54	1.00	17.12	3.67	0.16	2.82	2.28

Resists resolved p28, at high doses

MTR2Z(T)1Y(F) w/o PEB showed some wiggling and pattern collapse, while it showed good results w/ PEB

Lowest LWR_{unb} values are for MTR2Z(T)0Y(E) w/ PEB and MTR2Z(T)1Y(F) w/ PEB

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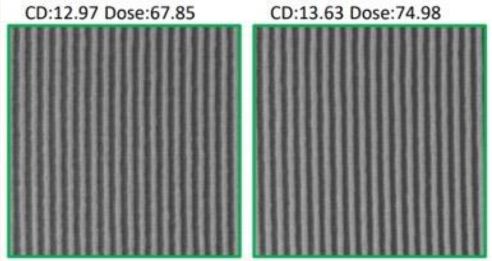
MTR2Z(T)1Y(E) + PEB



LWR = 1.66nm   LWR = 1.41nm

- PEB reduced dose by 6%
- LWR improved with PEB
- Best LWR at p28 = 1.41nm
  - Z factor = 4.11e-9

MTR4L3Y(2)-0 with no PEB Nov:

- *LWR = 2.03nm*
- *Dose = 55.5mJ/cm^2*
- *Z factor 6.28e-9*

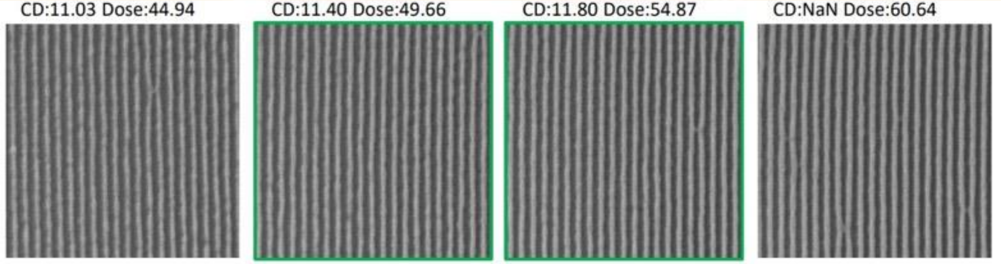
IRRESISTIBLE MATERIALS

Exposures undertaken by ASML PAUL SCHERRER INSTITUT PSI

p26nm and p24nm

p26

MTR2Z(T)1Y(E) + PEB



LWR = 2.45nm LWR = 1.95nm LWR = 1.81nm

P26: Slight pattern collapse

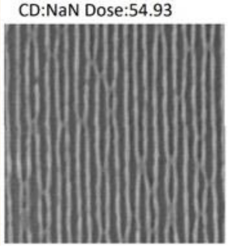
LWR improved to 1.81nm

MTR4L3Y(2)-0 with no PEB Nov:

- *CD = 12.17nm*
- *LWR = 2.24nm*
- *Dose = 38.9mJ/cm^2*

p24

MTR2Z(T)1Y(E) + PEB



pattern collapse obvious at p24

Further optimisation required

IRRESISTIBLE MATERIALS

Summary

Efforts have focused on process optimization the NXE scanner tools in order to reduce defects and LWR.

The development and rinse process shown to have an impact on the roughness of the lines patterned using the standard MTR material. A difference of 0.5 nm in the LER was observed using an alternative developer on track.

The high opacity MTR resist showed lower Z factor than the standard MTR resist based on NXE exposures, and less apparent defects at 16nm hp.

Introducing higher activation energy MTR molecules in combination with high opacity crosslinkers enables the introduction of a 60 – 80°C PEB with a decrease in Z factor.

New formulations undergoing first testing at PSI are showing promise

IRRESISTIBLE MATERIALS

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Thank you
Any Questions?

IRRESISTIBLE MATERIALS