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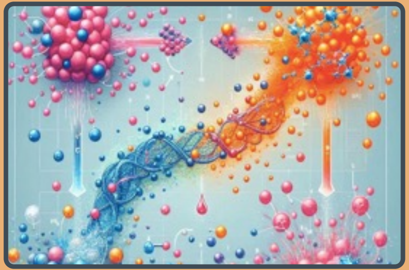
Advances by Multi-Trigger Resist towards high resolution EUV lithography

C. Popescu, A. McClelland, G. O’Callaghan, C. Storey, H. van Nguyen, G. Dawson, A.P.G. Robinson



MTR Overview

- ❖ The Multi Trigger Resist Platform
- ❖ MTR Current Performance for dense line spaces
- ❖ MTR Current Performance for contact holes

Underlayer importance

- ❖ Underlayer selection
- ❖ Underlayer effects on the resist performance

Etch capability

- ❖ AEI measurements for p36 l/s
- ❖ Electrical conductivity measurements

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TOK Investment & Partnership

- Tokyo Ohka Kogyo Co., Ltd. (TOK) has made a significant investment in Irresistible Materials
- TOK and IM have entered into a Joint Development Program to accelerate MTR Commercialization
  - MTR will serve as strong complement to TOK's leading CAR platform
- IM will continue to work closely with customers and partners to drive innovations and enhancements in MTR to low NA & high NA EUV patterning requirements
- TOK will serve as a manufacturing scale up partner for IM

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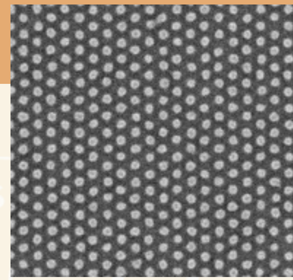
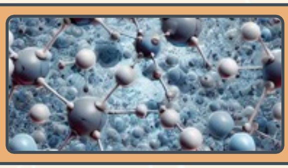
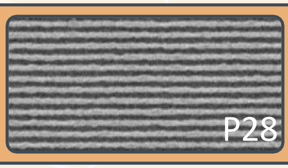
The Multi Trigger Resist Platform

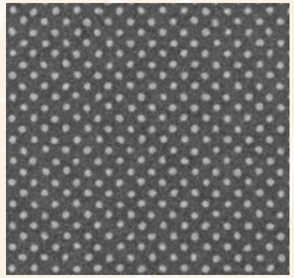


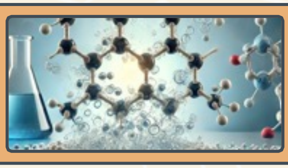


Multi-Trigger Resist (MTR™) is a negative-tone, high-Opacity organic molecular resist, designed for EUV (Low and High-NA)

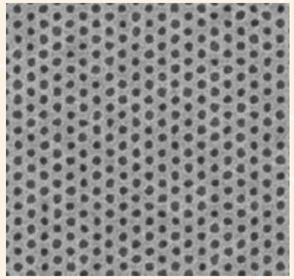


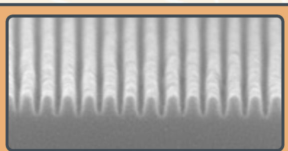
Significant speed extensibility – sub 30 mJ/cm^2 high resolution patterning demonstrated, for improved cost-of-ownership (CoO)



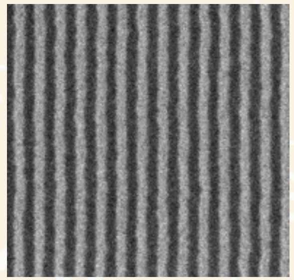


Innovative catalytic technology, compatible with organic resist track processes





Low top-loss and high etch-durability to enable thin film pattern transfer. Full stack transfer from sub-20 nm resist film thickness



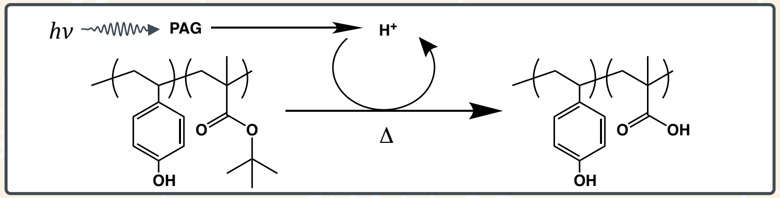
PFAS free photoacid chemistry and processing

The Multi Trigger Resist Platform

A new photoresist approach, building on chemical amplification,
but introducing the multi-trigger effect – controlled catalytic reaction via unique proprietary molecules

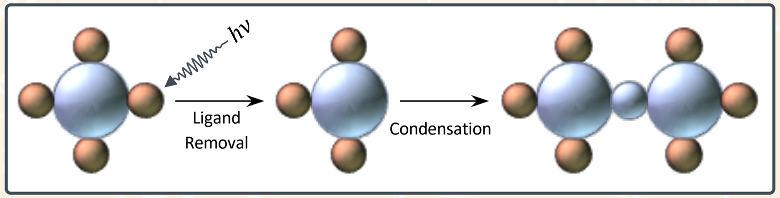
Traditional Chemically Amplified Resist (CAR)

- A photoacid reacts with a resist molecule and is regenerated
- Bake Temperature and Quenchers control the reaction



Non-Chemically Amplified Resist (MOR)

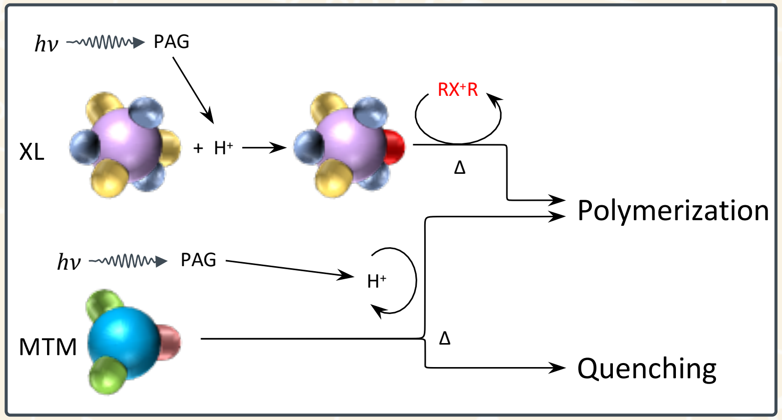
- The photon (photoelectrons) interact directly with the resist
- No amplification of the reaction – high absorption for sensitivity



Multi Trigger Resist (MTR)

- Photoacid is produced in the same way as CAR
- High opacity and small molecule like MOR

- The Multi Trigger Molecule exhibits dose-dependent behaviour:
    - In high dose areas it accelerates the CROP reaction
    - In low dose areas it quenches the CROP reaction



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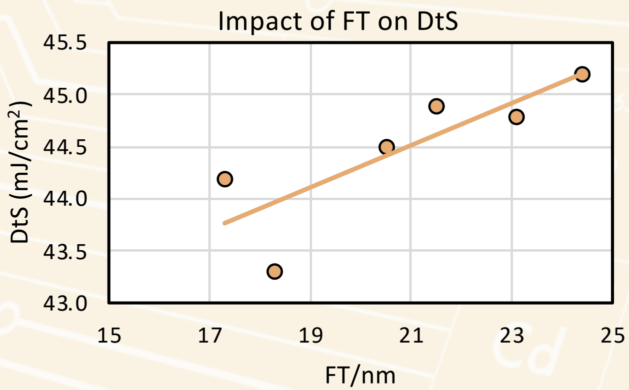
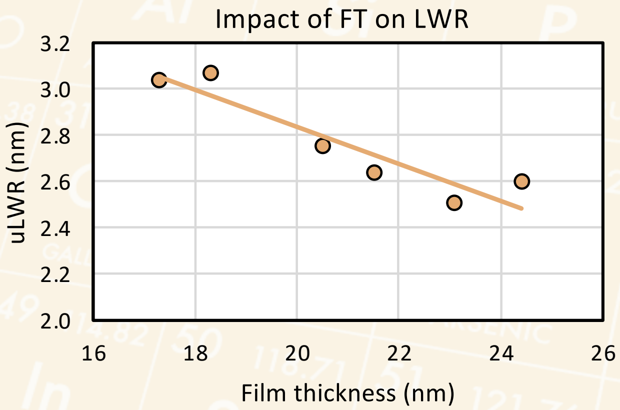
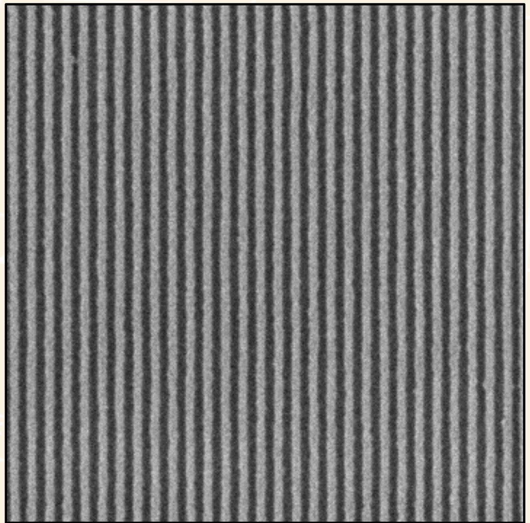
P28 l/s results – impact of film thickness

Goal: Investigate FT impact on DtS, LWR, Defectivity and FFL

FT (nm)
24.4
23.1
21.5
20.5
18.3
17.3







Resist film thickness: 23nm
Dose 45mJ/cm^2
CD 14.15nm
unbiased LWR 2.32nm
unbiased LER 1.91nm

- Increasing FT causes a small increase in DtS
- Significant change in LWR with Film thickness
- LWR improve with increased FT until bridging starts > 24nm FT
- Lowest LWR using 23.1nm film thickness at 14nm CD = 2.3nm

Optimum film thickness range for MTR resist is 17 – 25nm for p28 l/s

Evaluation conditions:

- UL: Brewer Optistack AL412
- Resist: MTR-VJCJ-4
- PAB: 80C-60s
- Developer: DP819A
- PEB: no
- p28 l/s
- Illumination 50017
- Analysis Software: Fractilia's MetroLER

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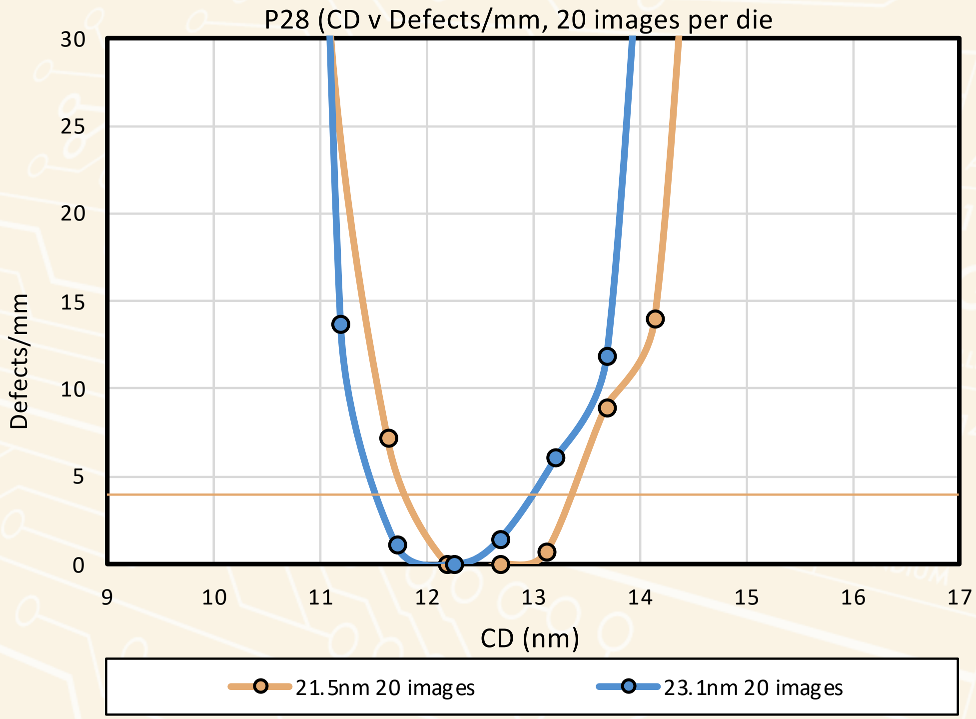
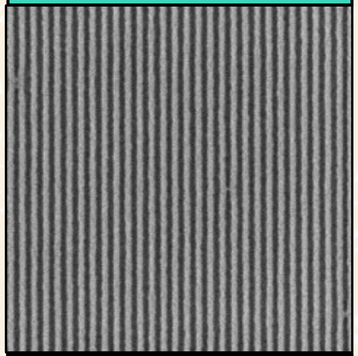
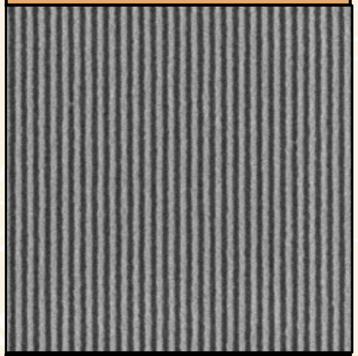
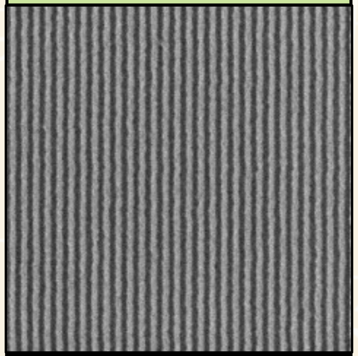
P28 l/s results – impact of film thickness on bridging



FFL <5/mm 21.5nm FT : 0.93nm (12.19 – 13.12)
FFL <5/mm 23.1nm FT : 0.97nm (11.71 – 12.68)

24.4nm	21.5nm	17.3nm
		
Dose 45mJ/cm^2	Dose 45mJ/cm^2	Dose 43mJ/cm^2
unbiased CD 13.95nm	unbiased CD 14.11nm	unbiased CD 14.32nm
unbiased LWR 2.55nm	unbiased LWR 2.32nm	unbiased LWR 3.07nm
unbiased LER 1.92nm	unbiased LER 1.97nm	unbiased LER 2.18nm

Some bridging

Higher roughness

Higher FT = lower maximum CD with no defects - due to bridging
Lower FT = higher minimum CD with no defects - due to breaks

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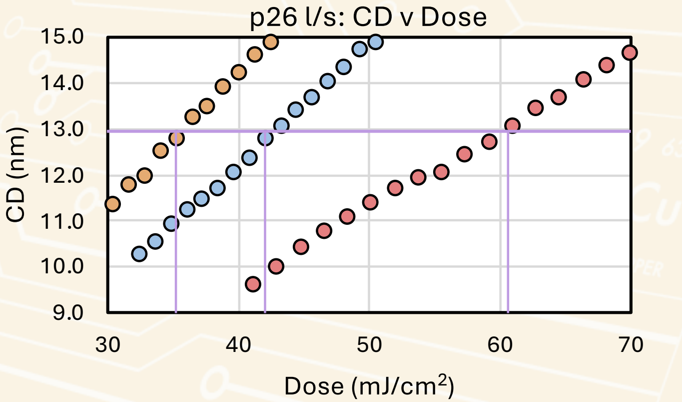
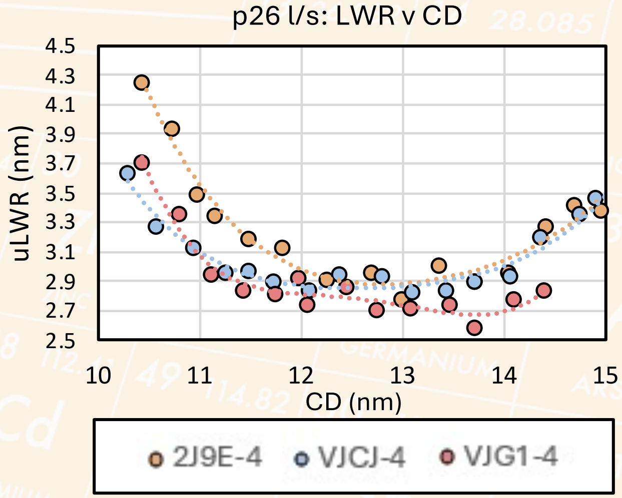
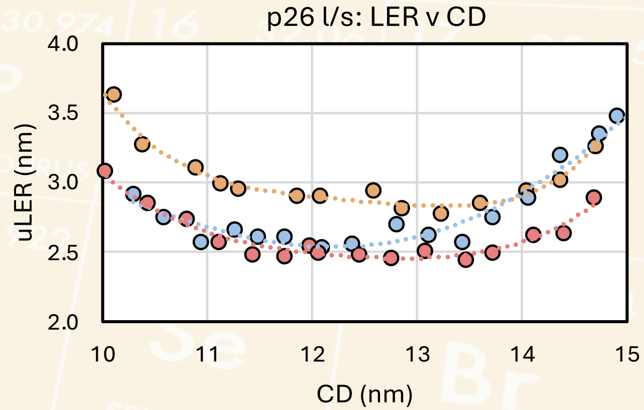
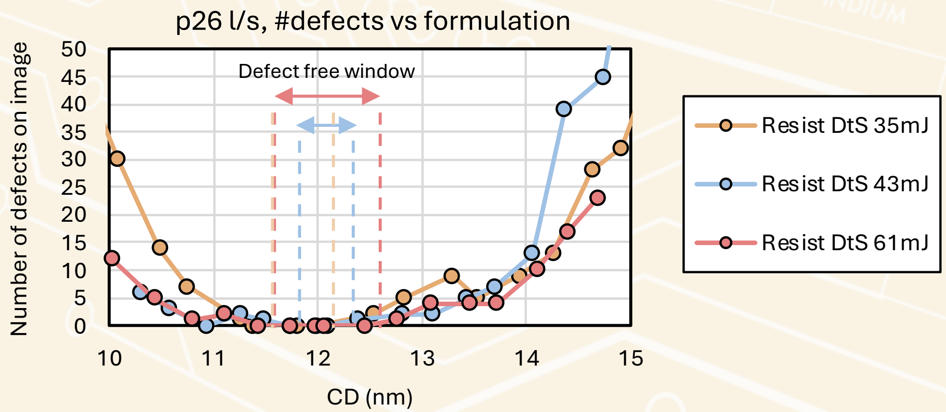
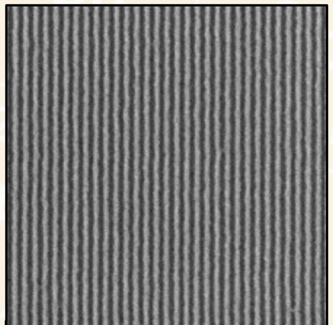
Comparison of MTR resist formulations at p26 l/s











VJG1-4
Dose: 57 mJ/cm²
CD: 12.4nm
uLWR: 2.8nm
uLER: 2.5nm

Lowest Z factor for VJCJ-4

Wider Failure Free region for slowest resist

LWR and LER follow expected trend with DtS

Lowest dose resist impacts LER more than LWR (for 2J9E-4)

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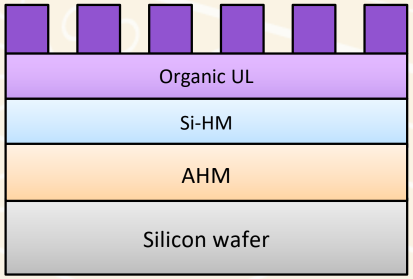
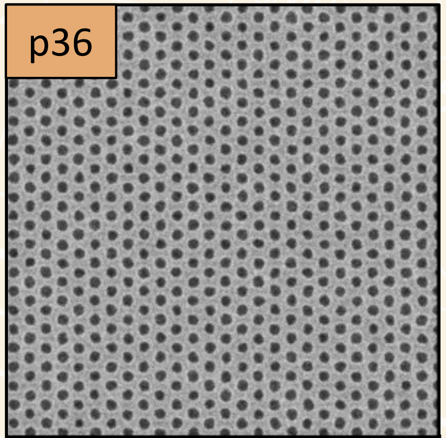
Use of MTR resist for contact hole patterning

MTR resist (negative tone) uses low-n bright field mask to pattern hexagonal contact holes

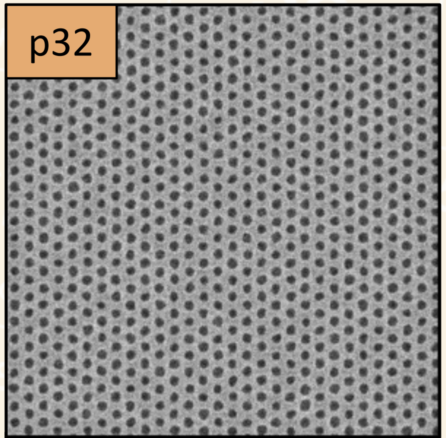
- P32 and p36 patterned on stack wafers
- Resist film thickness in 21 – 28nm range
- ADI results presented



MetroLER analysis for defects
Images shown at centre of Failure Free window



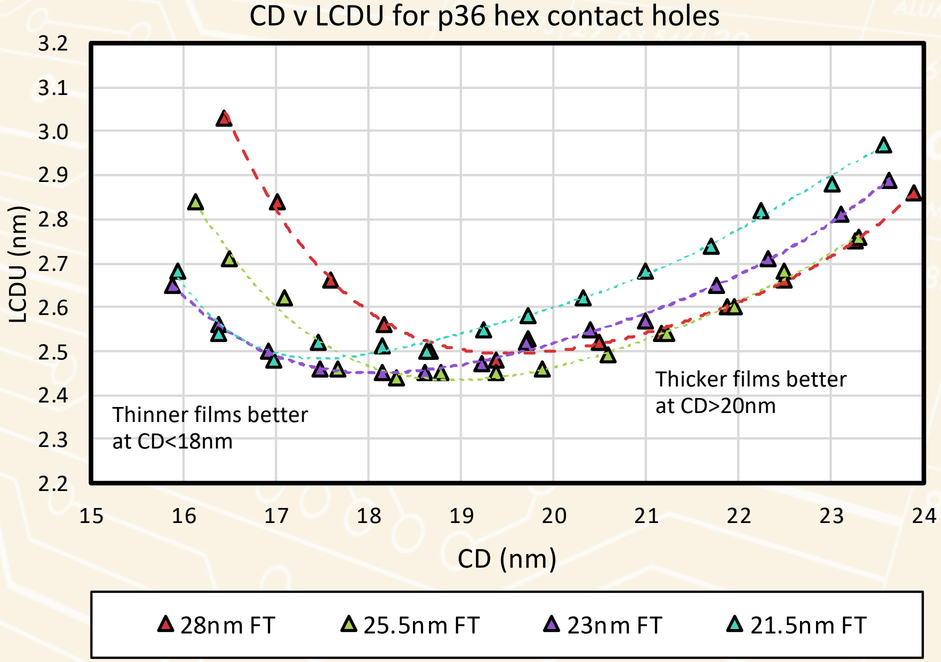
25.5nm FT
Dose 50mJ/cm^2
CD 19.9nm
LCDU 2.46nm

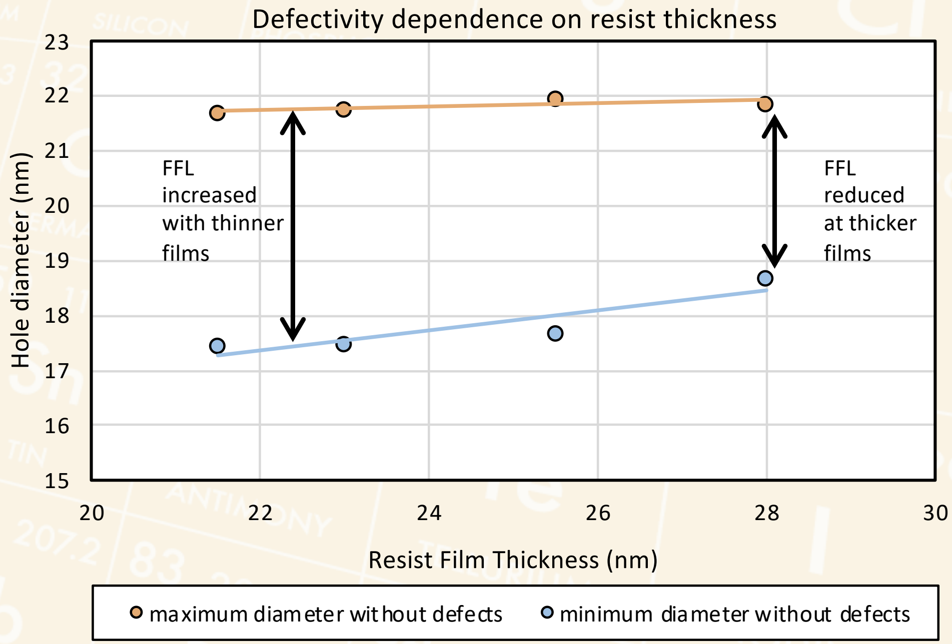


21.5nm FT
Dose 48.5mJ/cm^2
CD 17.8nm
LCDU 2.76nm

Contact hole ADI results: p36 hex

MTR-VJG1-4 patterned with four different film thicknesses
Dose to pattern 18nm diameter = 55mJ/cm^2

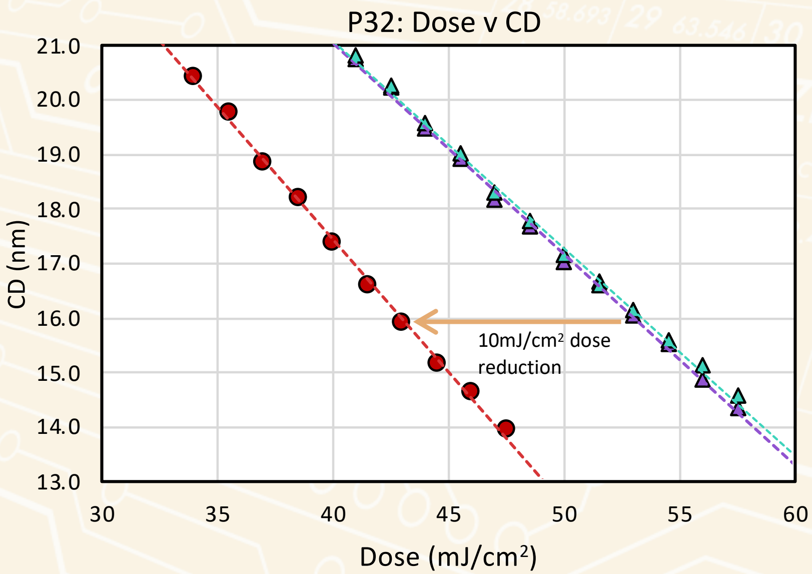


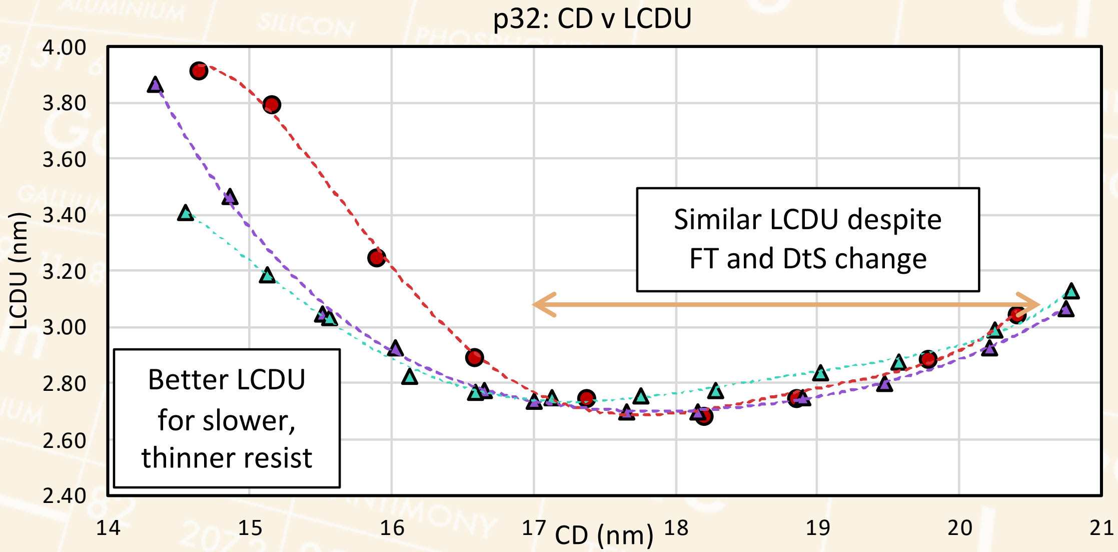


Use of thinner films increases failure free latitude by 30% with lower LCDU at hp

Contact holes ADI results: p32 hex

MTR-VJG1-4 and MTR-VJCJ-4 patterned with three different film thickness
Dose to pattern 16nm diameter = 53mJ/cm² and 43mJ/cm²





● VJCJ-4 25.5nm FT ▲ VJG1-4 23nm FT ▲ VJG1-4 21.5nm FT

Better LCDU using slower, thinner resist for 16nm holes

MTR Overview

- ❖ The Multi Trigger Resist Platform
- ❖ MTR Current Performance for dense line spaces
- ❖ MTR Current Performance for contact holes

Underlayer importance

- ❖ Underlayer selection
- ❖ Underlayer effects on the resist performance

Etch capability

- ❖ AEI measurements for p36 l/s
- ❖ Electrical conductivity measurements

IRRESISTIBLE MATERIALS

Underlayer Effects on the Resist Performance

Need to consider the chemistry occurring at the interface between the resist and the UL
In thinner stacks the layers underneath the top UL may also have an influence

Is the Underlayer affecting the Sensitivity of the Resist?

Is the Underlayer affecting the Defectivity of the Resist?

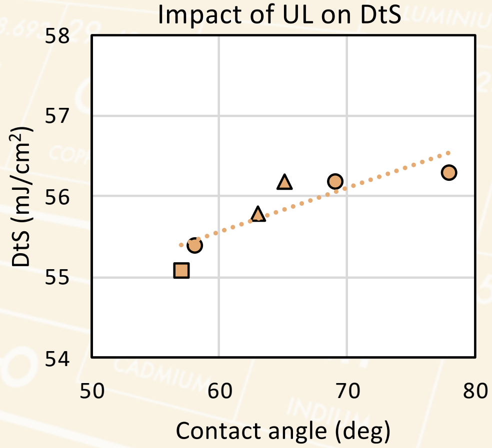
Is the Underlayer affecting the Metrology?

Impact of varying organic underlayer properties

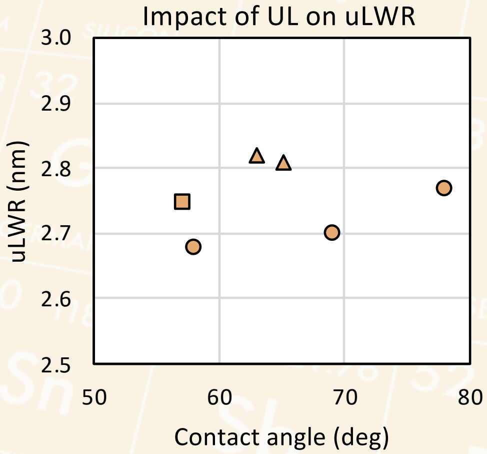
6 organic underlayers with varying material properties were tested at 10nm thickness
21nm thick MTR resist was patterned at p28 l/s using standard processing conditions

Nissan Chemical CORPORATION

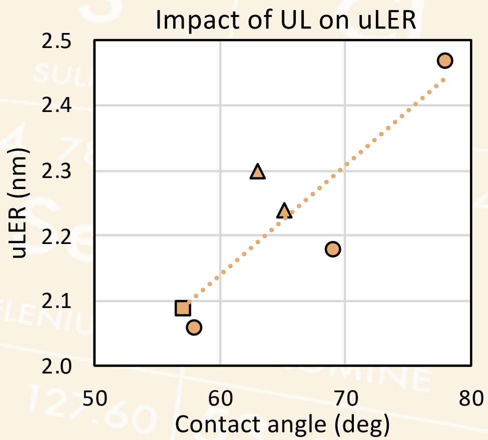
Polymer Type	Contact Angle °
A □	57
C1 ○	78
C2 ○	69
C3 ○	58
D1 △	65
D2 △	63



Small impact on DtS
Increases with contact angle

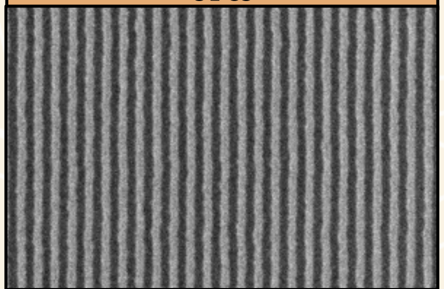


Small change in LWR
Impacted by polymer type



Significant change in LER
Varies with contact angle

UL C3



Best results on low contact angle underlayer

Contact angle is major driver of sensitivity, roughness and defectivity, but polymer type also impacts roughness

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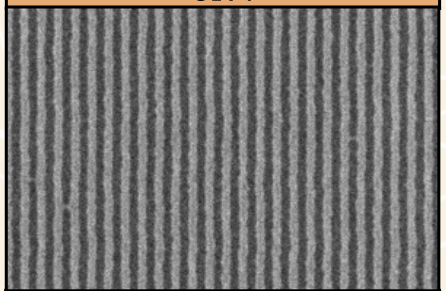
Impact of varying FSTP properties

8 primers with varying material properties were tested with a film thickness of 1-2nm
21nm thick MTR resist was patterned at p28 l/s using standard processing conditions

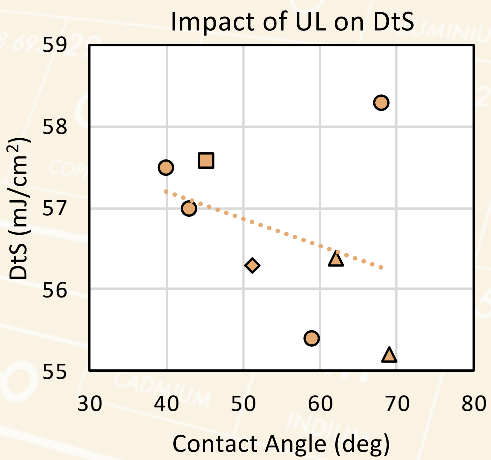
Nissan Chemical CORPORATION

Concept	Contact Angle °
E □	45
F1 ○	40
G ◇	51
F2 ○	59
F3 ○	68
H1 △	62
H1 △	69
F4 ○	43

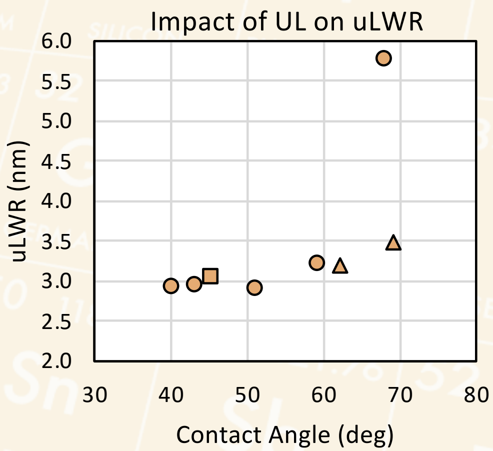
UL F4



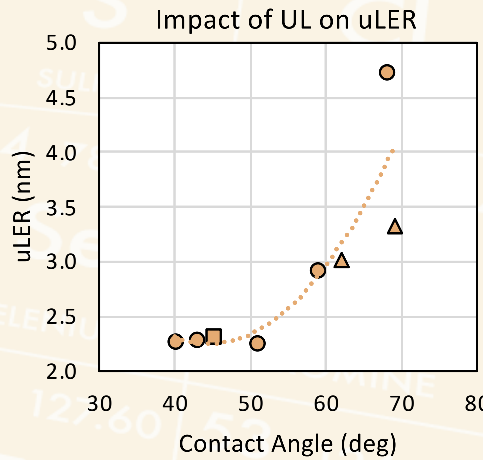
Best results on low contact angle



Small impact on DtS
Decreases with contact angle



Small change in LWR (except F3) with contact angle



Significant LER increase with contact angle

Contact angle is a major driver of sensitivity and roughness

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Etch capability

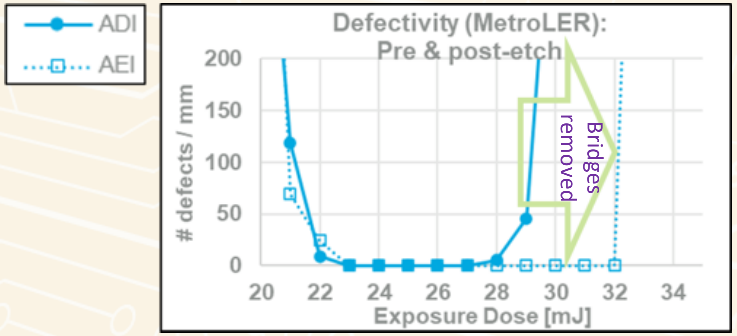
- ❖ AEI measurements for p36 l/s
- ❖ Electrical conductivity measurements

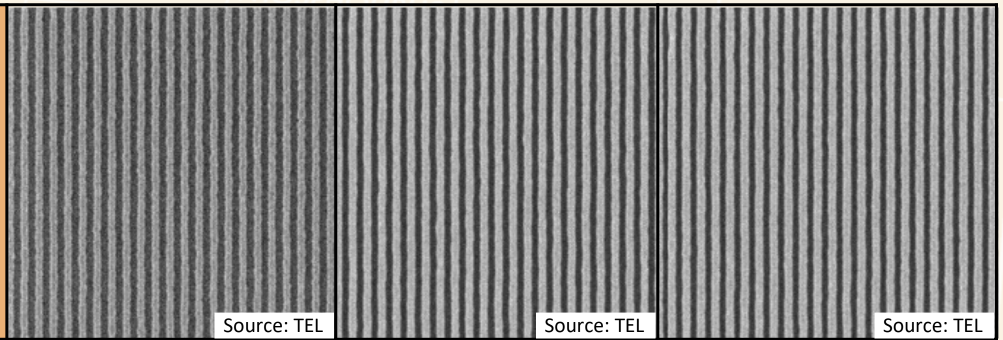
High Speed 36P Line/Space Pattern Transfer

Single patterning (36P dense L/S) using MTR-2J9E

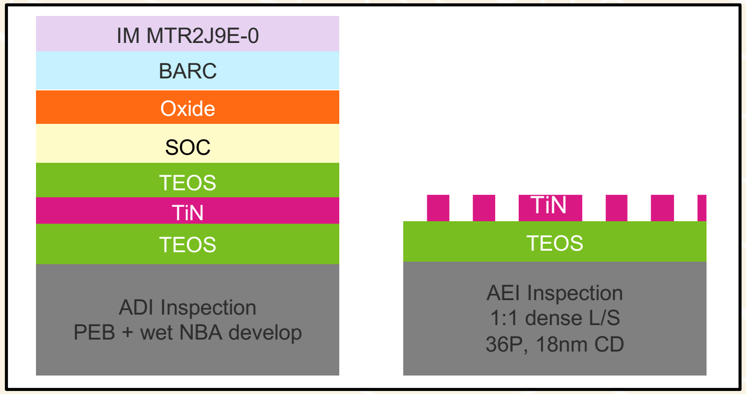
Defectivity is reduced via removal of bridges in etch

(special acknowledgement to Kathleen McInerney, TEL, for this work)





Current POR for 36P L/S at sub-30mJ			
Condition	Wet develop inspection	After etch (target CD)	After etch (best roughness)
Dose [mJ/cm^2]	28	28	30
Mean Line CD [nm]	16.9	18.4	19.3
UB LER (avg) [nm]	2.53	1.96	1.82
UB LWR (3s) [nm]	3.36	2.36	2.23
Defects / mm	None	None	None
FFL [nm]	2.8	4.1	4.1
# of images	17	17	17



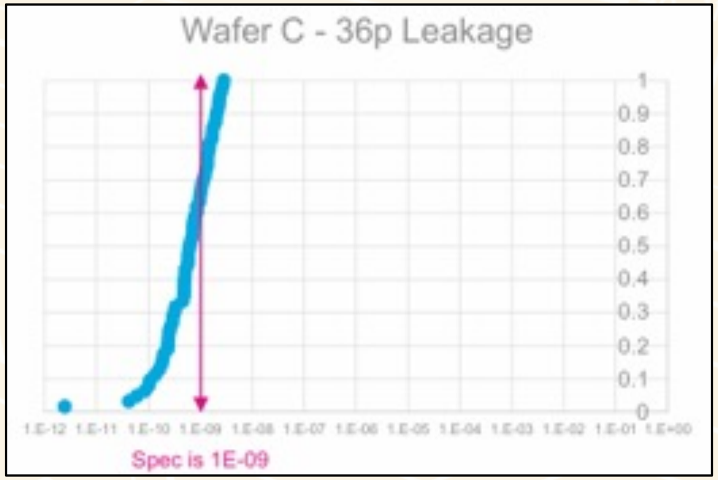
Achieved 1.8nm LER AEI using dose of 30mJ/cm^2 with no defects

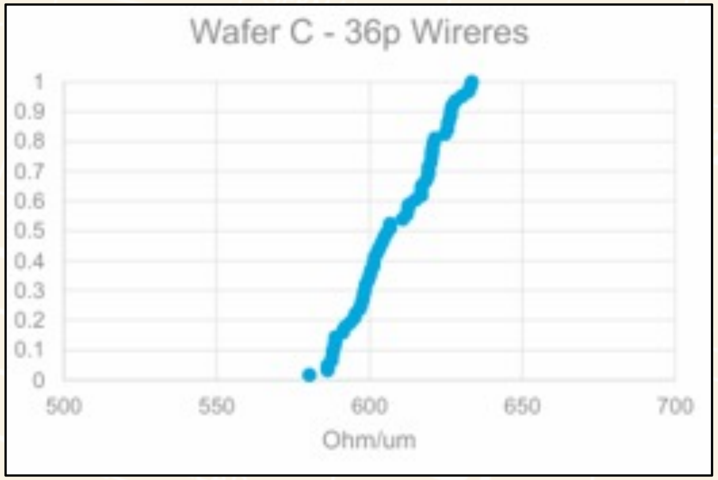
Electrical etch tests – 1cm maze ILT results

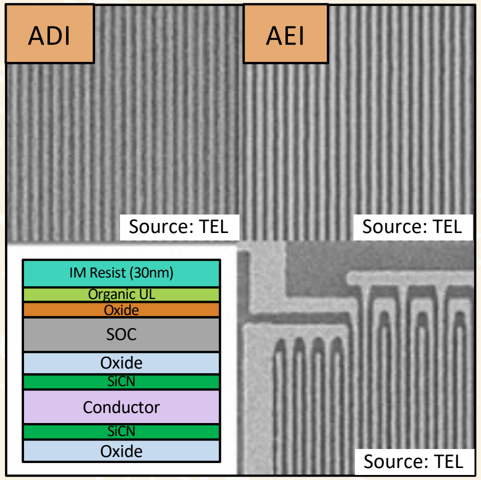
Electrical testing of samples etched from MTR resist patterns was undertaken
(special acknowledgement to Kathleen McInerney, TEL, for this work)

Dose mJ/cm²	Focus um
32	0.12

Mean Line CD (nm)	UB LWR nm	UB LER nm	Defective die / 71	Mean Line CD (nm)	UB LWR nm	UB LER nm	Defective die / 71
ADI				AEI			
16.54	3.33	2.52	0	17.96	2.23	1.97	1







Test showed **successful etching** through stack. Electrical testing in line with target

Summary

- Multi-Trigger Resist is a negative-tone, high-Opacity organic molecular resist, designed for EUV (Low and High-NA)
- MTR resist formulations have successfully patterned p28 l/s, p26 l/s and p32 hex contact holes
    - MTR-VJCJ-4 patterns p28 l/s at <50mJcm^2 with uLWR of 2.3nm
    - MTR-VJG1-4 patterns hex contacts at <50mJcm^2 with uLCDU of 2.5nm
- Underlayers have a major impact on resist performance
    - Contact angle is major driver of sensitivity, roughness and defectivity, but polymer type also impacts roughness
- Low top-loss and high etch-durability enable thin film pattern transfer
    - Results at p36 l/s show a 1.8nm LER AEI etched into wafer stack using dose of 30mJ/cm^2 with no defects

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Fractilia

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imec

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TEL

Thank you

Any Questions?

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