EUV Resist Materials Design for 15 nm Half Pitch and Below

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Research & Development management headquarters

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2) Synthetic Organic Chemistry Laboratories

FUJIFILM Corporation

Outline

Key messages

1. Motivation

2. Strategy for 15nm HP and below → Hydrophobic polymer
   Special rinse
   High reactivity CAR

3. Design on RLS improvement → 16 nm res. @20mJ
   15 nm res. (partially 14nm) @33mJ

4. Future technology → Best Z-factor 3.8 x 10^{-9} mJnm^3

5. Summary

Outline

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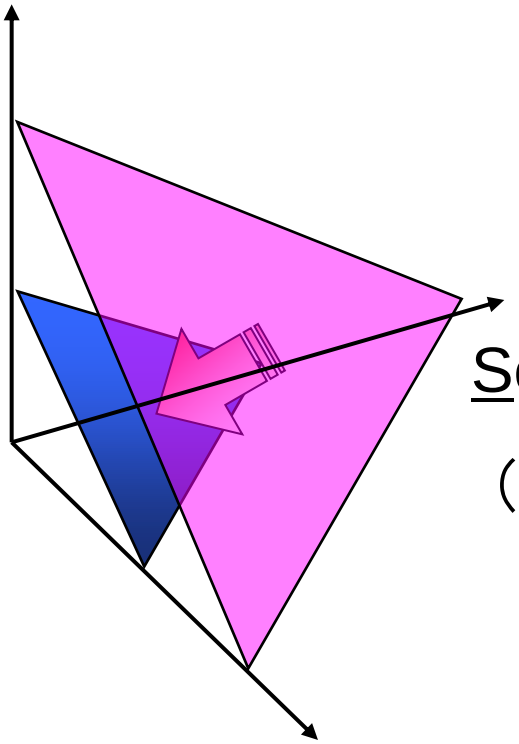
2. Strategy for 15 nm HP and below
3. Design on RLS improvement
4. Future technology
5. Summary

Challenges in EUVL

Performance

Resolution（<22nm）



Sensitivity

（<10~15mJ）

LWR (<3.0nm）

Quality

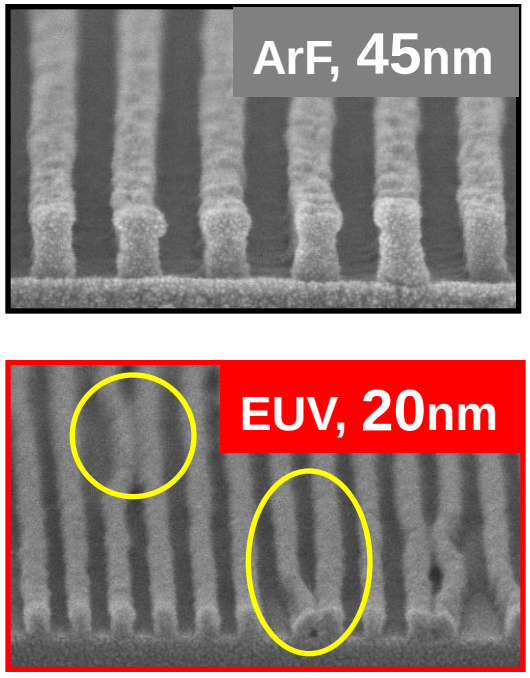
Defectivity

(Outgassing)

「RLS tradeoffs」「Defectivity」

Technical issues in RLS

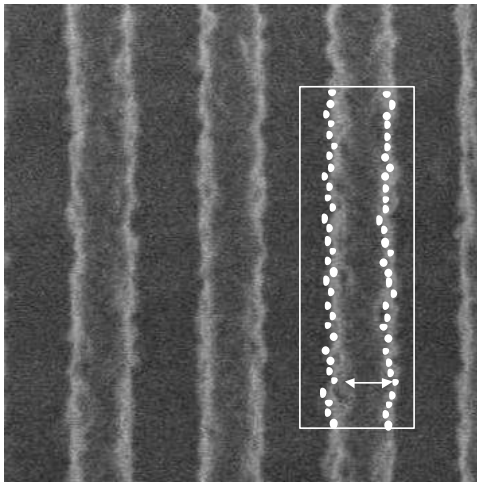
1. Resolution



Narrow pitch

『Pattern collapse』

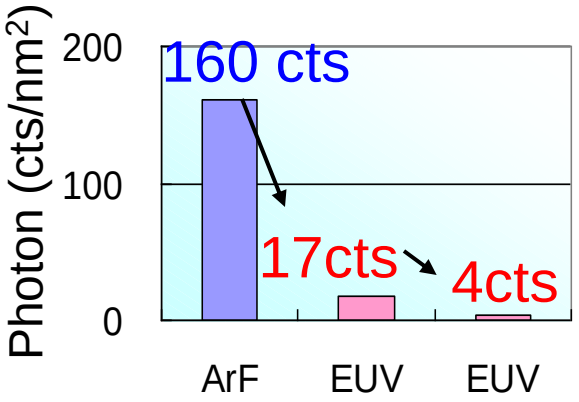
2. LWR



Photon shot noise
Low acid quantum yield

『Non-uniform deprotection』

3. Sensitivity



High photon energy
Fast E_{size} requirement

『Lack of photon』

『Collapse』, 『Non-uniform deprotection』, 『Lack of photon』

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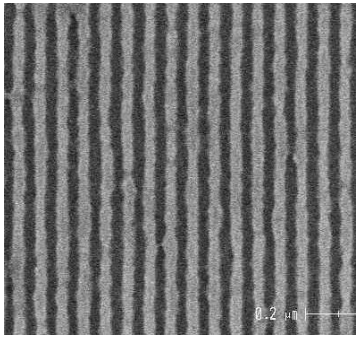
Breakthrough technology for RLS tradeoffs

1. Resolution

『Pattern Collapse』

- Hydrophobic polymer
- Low-surface tension special rinse

16 nm resolution

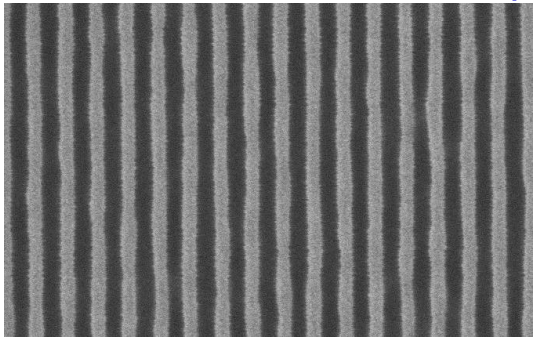


2. LWR

『Non-uniform deprotection』

- Smoothing by special rinse

3.2nm LWR @20nmhp



3. Sensitivity

『Lack of photon』

- High deprotection reactivity CAR

19 mJ/cm^2 Sensitivity

Outline

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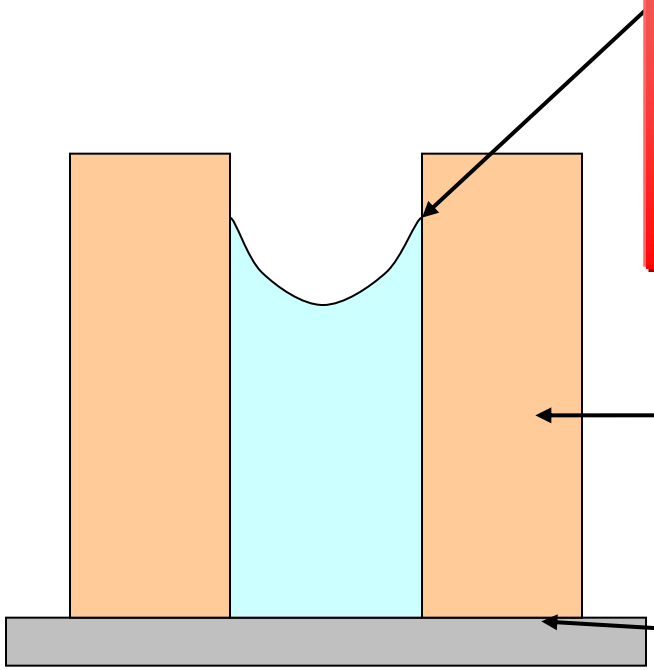
Origins of pattern collapse



Capillary force

Resist surface properties
: Hydrophobicity

Rinse liquid properties
: Low surface tension

V *Collapse !*

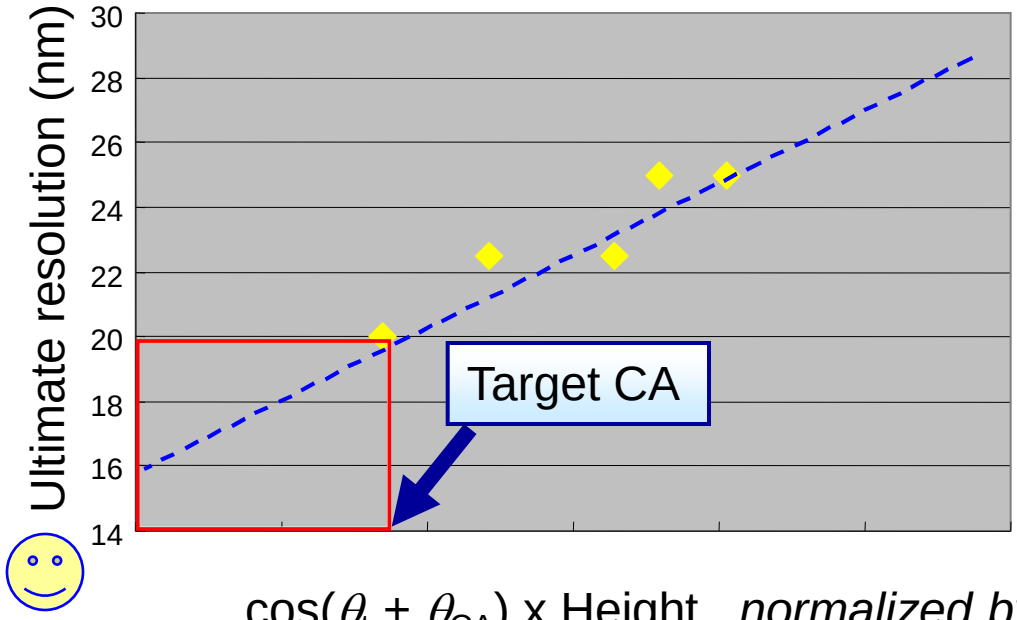
Mechanical strength

Adhesion

Most important is reducing capillary force

Relationship: contact angle vs. resolution (collapse)

50 keV E-beam (point beam)

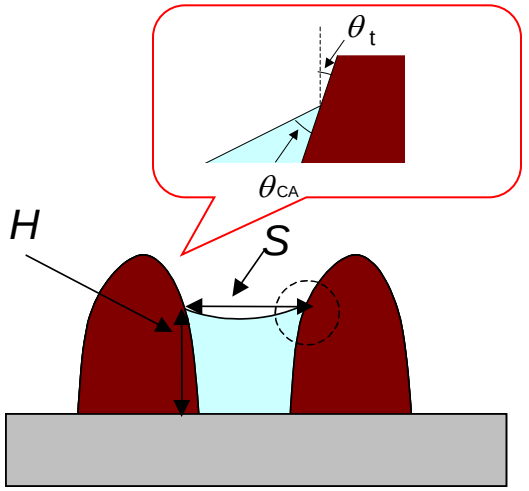


$$F = \frac{\gamma 2\cos(\theta_{CA} + \theta_t)}{S} \cdot HD$$

F: Capillary force
γ: surface tension
H: Pattern height
S: Pattern space width
D: Pattern length
θ_{CA} : Static CA on coated film
θ_t: Pattern sidewall slope

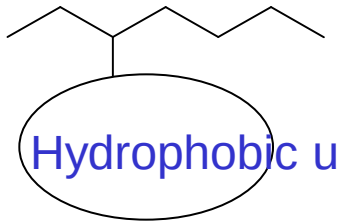
$\cos(\theta_t + \theta_{CA})$ x Height *normalized by profile*

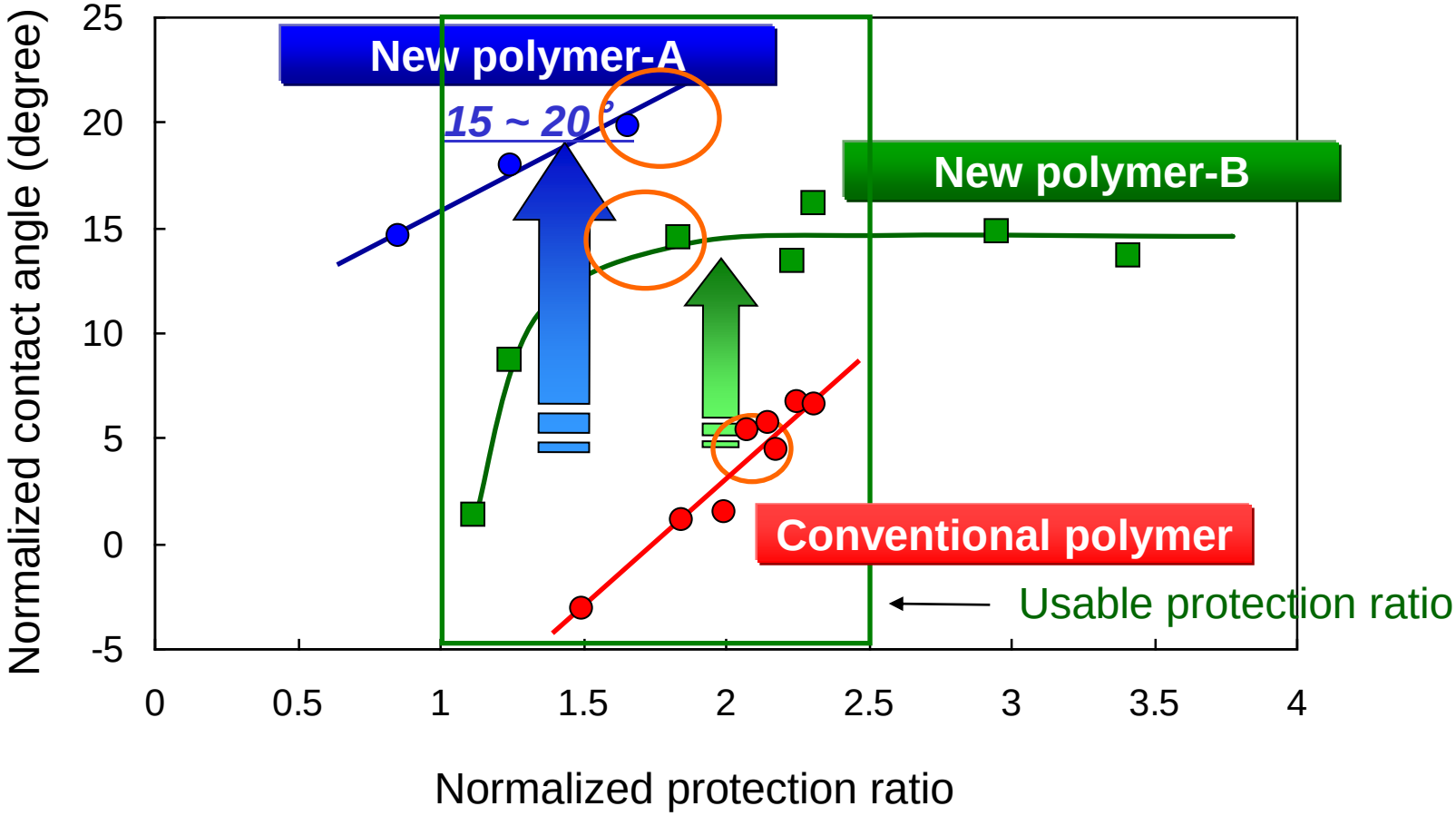
Hydrophobic ⟸ **Hydrophilic**



Strategy is to design hydrophobic resist

Hydrophobic polymer design





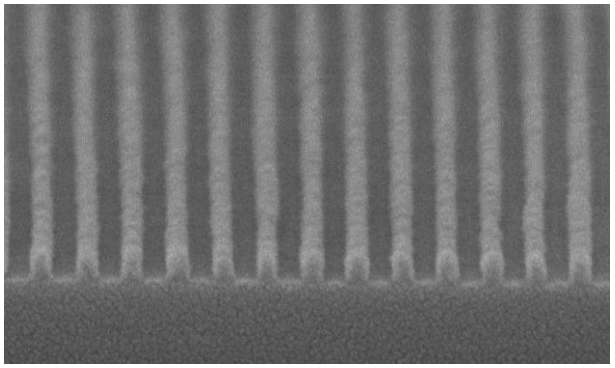
Our new polymer design increased CA up to 15° (normalized)

Proof of concept, high CA resist

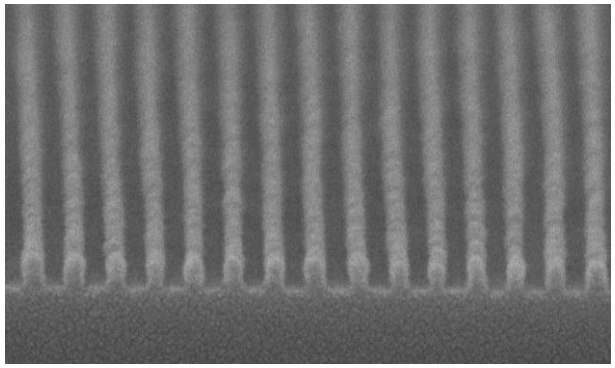
50 keV point beam
40 nm film thickness

FEVS-P1507D: High CA, new polymer-B

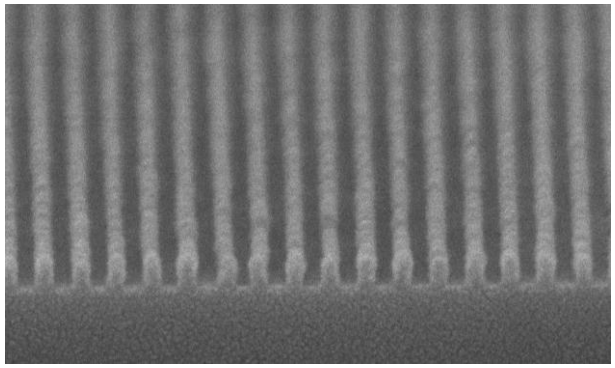
25.0 nm L/S



22.5 nm L/S

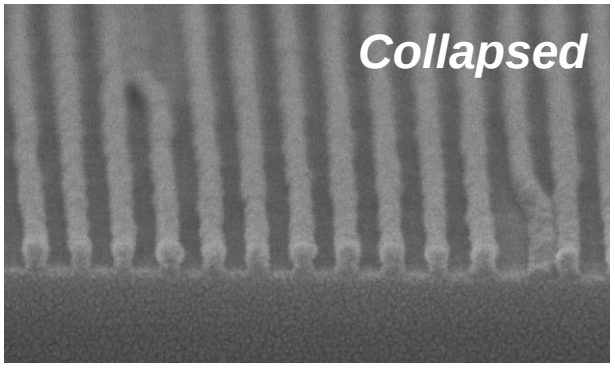


20.0 nm L/S

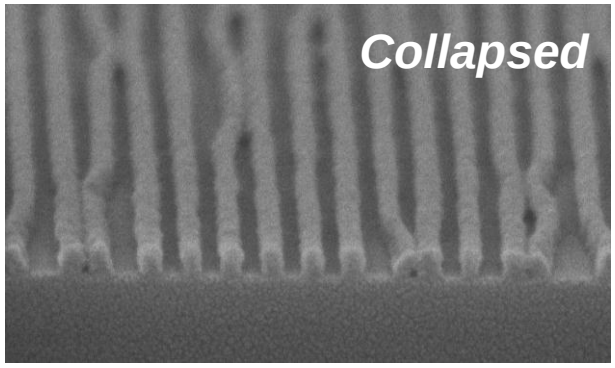


FEVS-P1293A: Low CA, conventional polymer

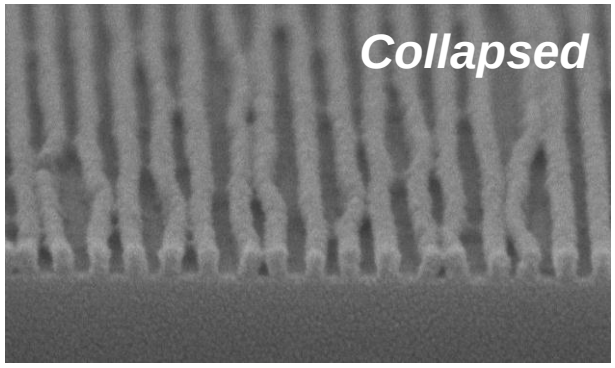
25.0 nm L/S



22.5 nm L/S



20.0 nm L/S



High CA polymer-B has a advantage on collapse

FUJIFILM

EUVL performances on LBNL-MET

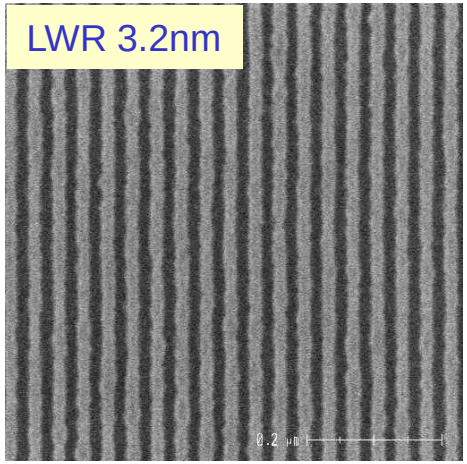
SEMATECH

BERKELEY LAB

FEVS-P1593E2: Highest CA, new polymer-A

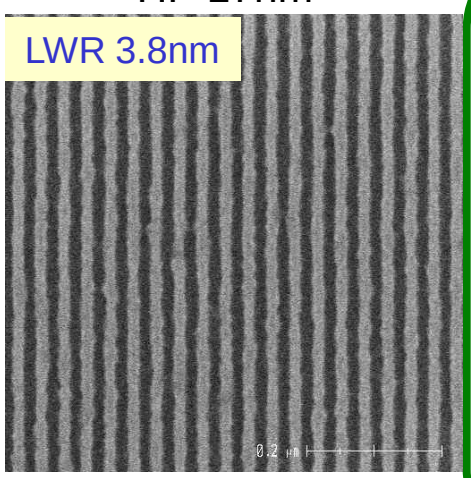
NA 0.3
Pseudo PSM@LBNL

HP 18nm



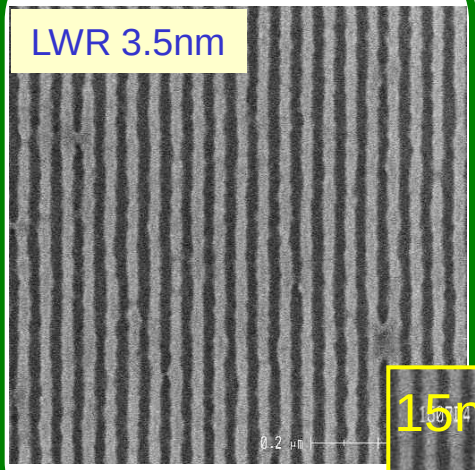
19.3 mJ/cm^2

HP 17nm



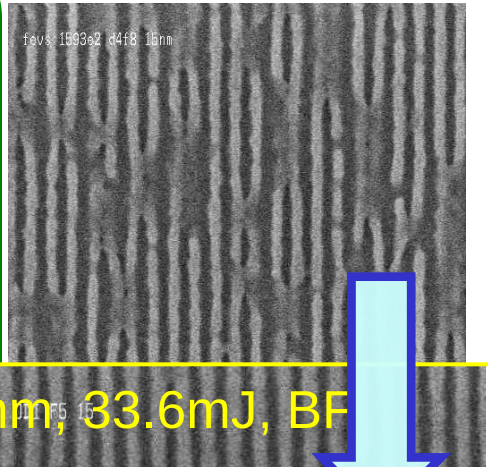
19.3 mJ/cm^2

HP 16nm

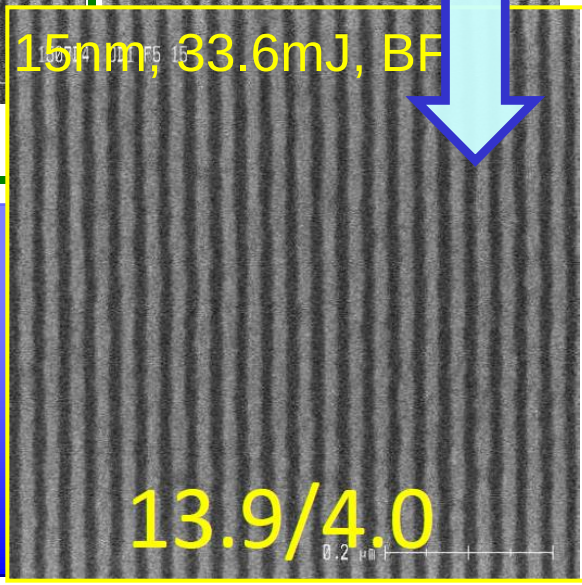


20.8 mJ/cm^2

HP 15nm



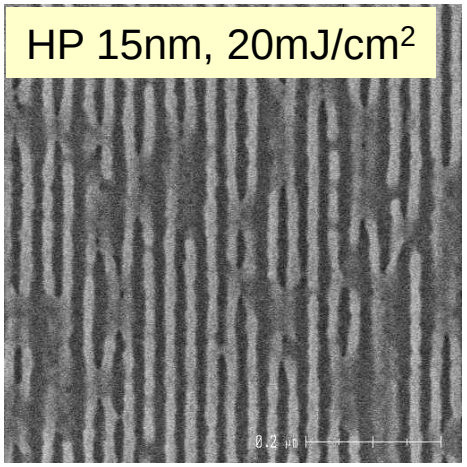
15nm, 33.6mJ, BF



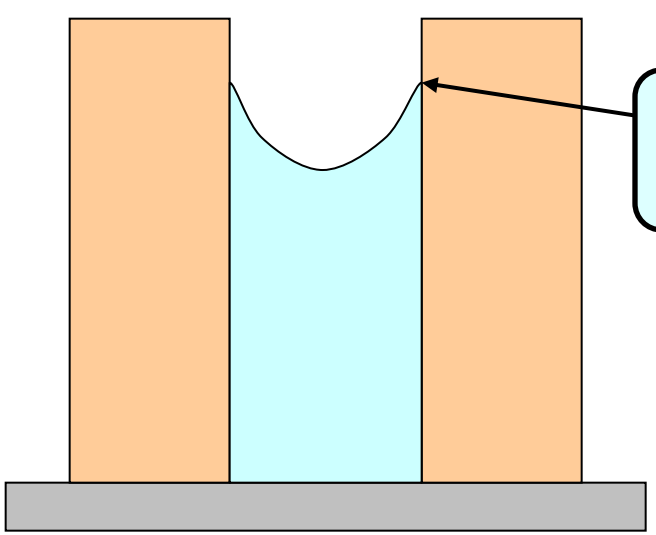
Resolution: **16 nm HP** (15 nm HP @33mJ/cm^2)
LWR: **3.2 nm** (2.2nm LER)
Sensitivity: **19 mJ/cm^2**

Z-factor: 3.8 x 10^{-9} mJ nm^3 (best to our knowledge)

Next challenges in pattern collapse



Thin film thickness (35 nm coating) + Hydrophobic polymer + Special rinse



Actions

- Capillary force
  - Thin film thickness
  - Hydrophobic polymer
  - Low surface tension special rinse

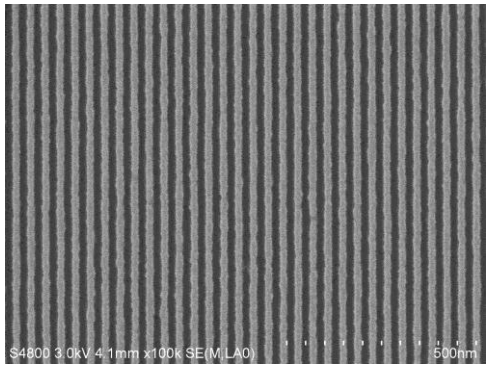
Combination of “hydrophobic polymer” and “special rinse”

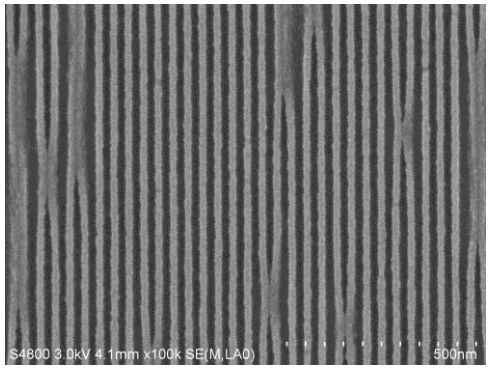
Special rinse

FEVS-P1593E2, ultra-hydrophobic polymer

BMET, dipole
20nm L/S

DIW rinse



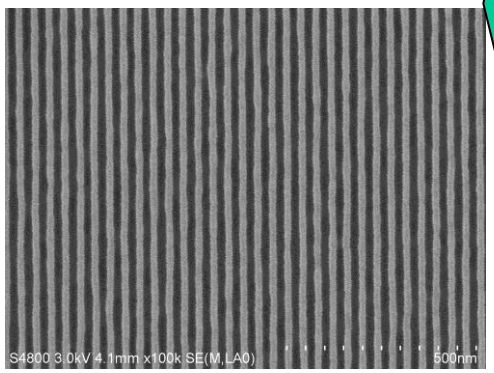


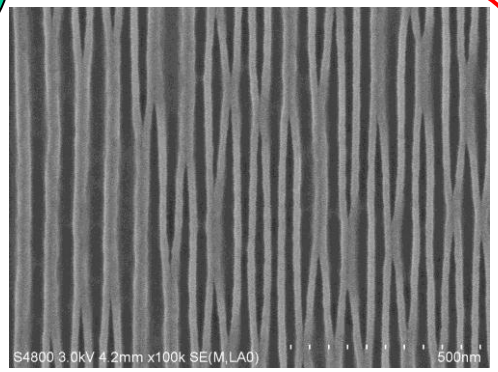
N.D.

improve

+ Special rinse

N.D.

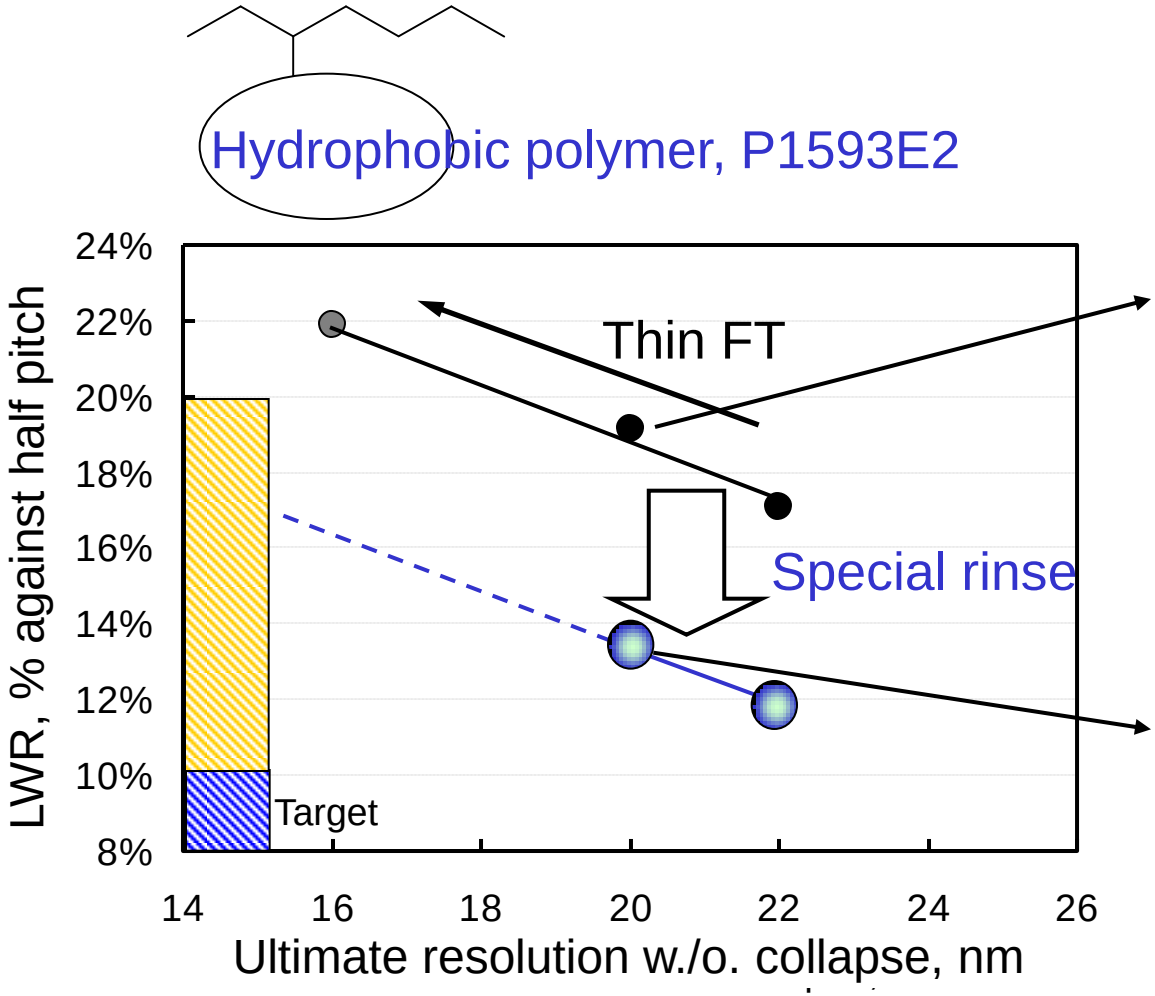


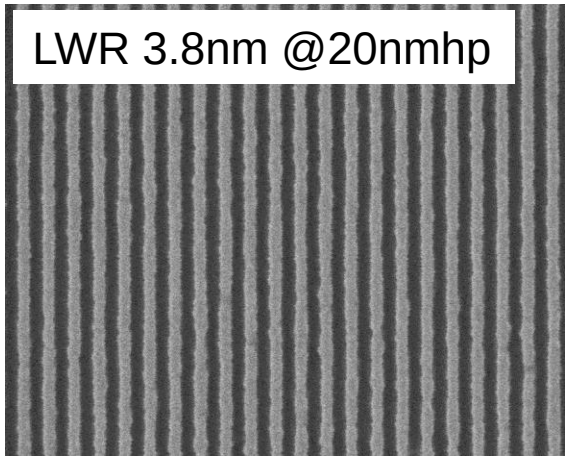


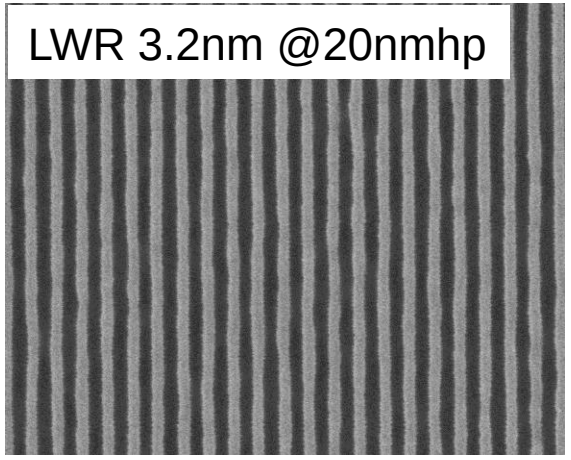
50nm coating　　70nm coating　　80nm coating

20 nm L/S was resolved without collapse on 70 nm coating FT

Simultaneous improvement on “resolution” – “LWR”







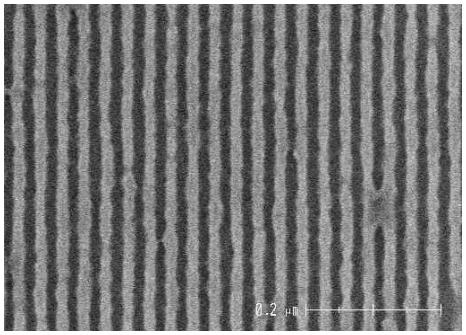
20nm res. / 3.2nmLWR was demonstrated
⇒ 15 nm res. / 2.7 nm LWR is estimated by adjusting FT

Breakthrough technology for RLS tradeoffs

1. Resolution
『Pattern Collapse』

- Hydrophobic polymer
- Low-surface tension special rinse

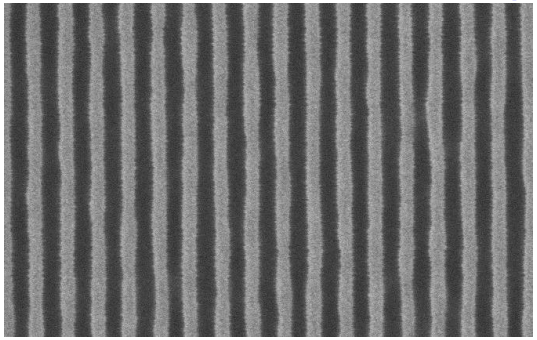
16 nm resolution



2. LWR
『Non-uniform deprotection』

- Smoothing by special rinse

3.2nm LWR @20nmhp

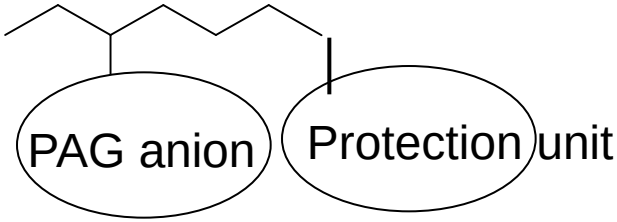


3. Sensitivity
『Lack of photon』

- High deprotection reactivity CAR

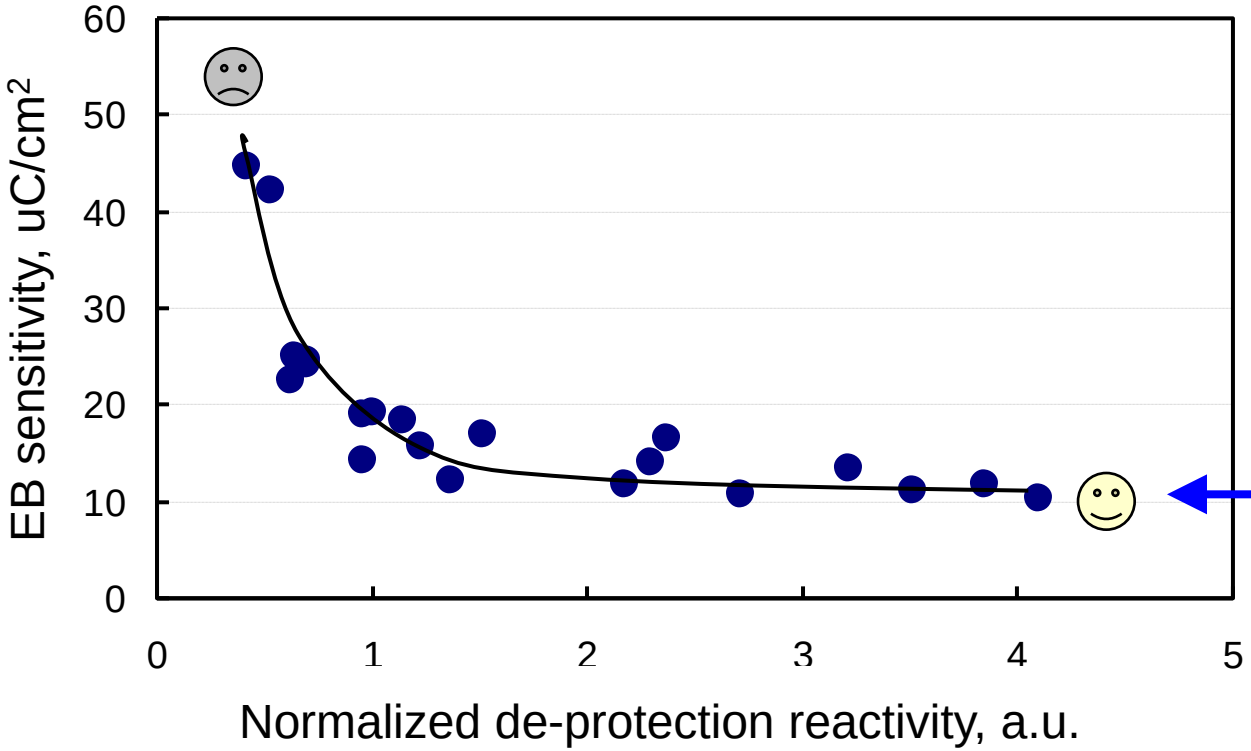
19 mJ/cm^2 Sensitivity

Solution to afford a few photon condition



50 keV E-beam data
PAG and amine loadings : constant

"Maximizing de-protection reactivity"



~20 mJ/cm^2
Sensitivity
@EUV

High sensitivity was obtained by using high reactivity CAR

Outline

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3. RLS improvement
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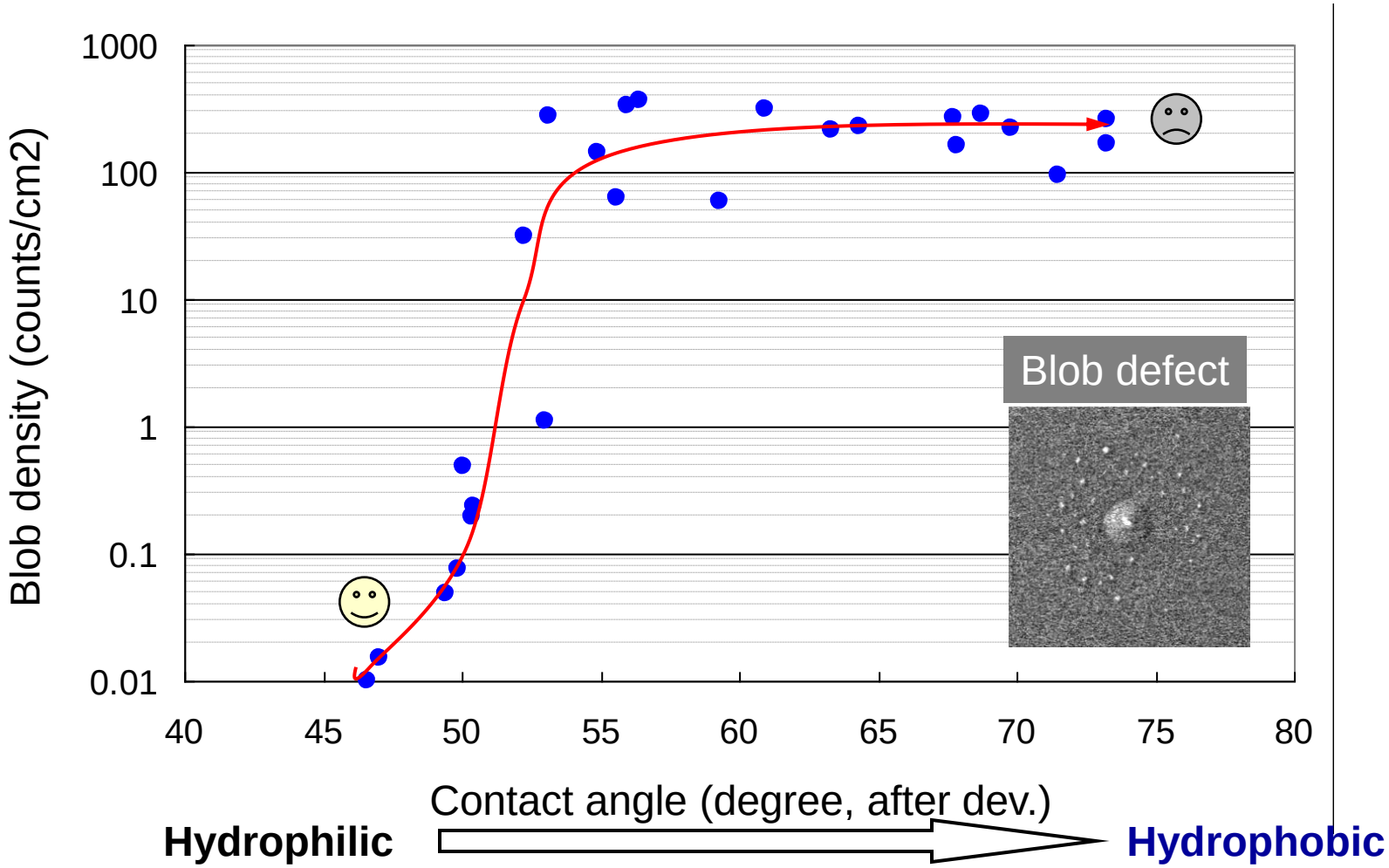
Defectivity issue



Hydrophobic resist has a defectivity issue

EUV additive: breakthrough, defectivity-resolution

EUV additive: **much hydrophobic**

Defectivity

Collapse

Hydrophobic imaging resin

Substrate

Polarity change

Exposure
PEB
Development

Hydrophilic

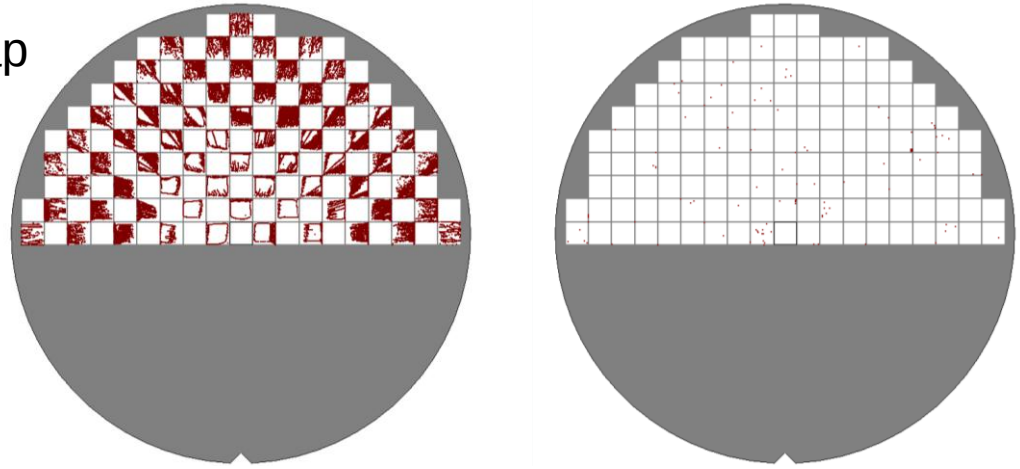
Defectivity

Collapse

Hydrophobic imaging resin

Substrate

Defect map



Without EUV additive

With EUV additive

New EUV additive drastically improved defectivity

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Summary

1. Our new resist FEVS-P1593E2 can resolved 16nm HP with LWR of 3.2nm, and sensitivity of 19mJ/cm^2.

   ⇒ Z-factor : 3.8E^{-9} mJ·nm^3 (best to our knowledge)

   ⇒ partial resolution of 14 nm was confirmed (latest resist)

2. Hydrophobic polymer is a key technology for resolving hp 16nm.

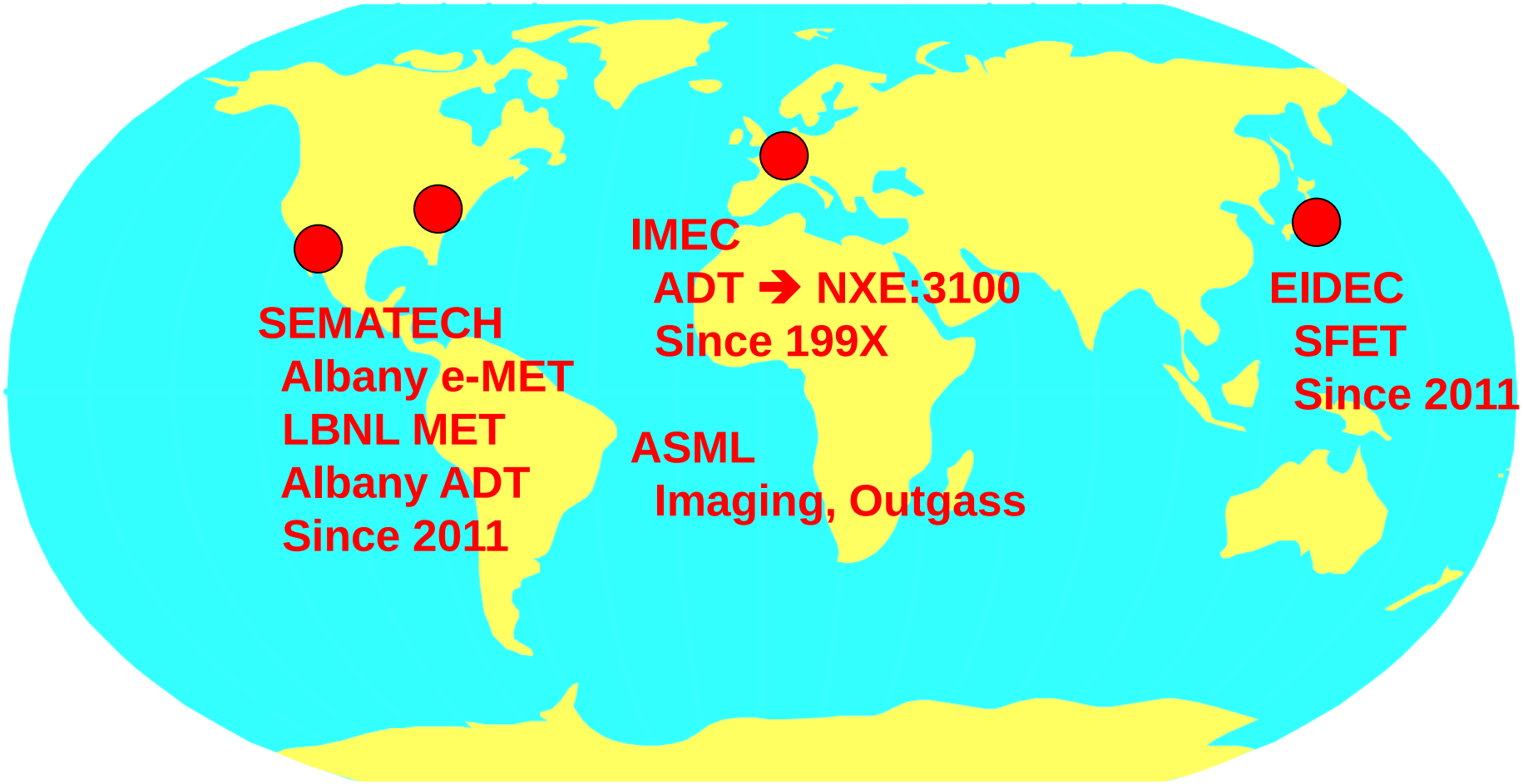
3. Combination of hydrophobic polymer and special rinse process afford to reduce LWR with maintaining high resolution without pattern collapse

   ⇒ 15 nm resolution and 2.7 nm LWR should be estimated

4. High de-protection reactivity design is a solution for high sensitivity down to 20 mJ/cm^2.

5. EUV additive works as breakthrough technology for improving “resolution”-”defectivity” tradeoff.

FUJIFILM Activities in the world



FUJIFILM has joined all big three consortium challenging EUVL

Acknowledgement

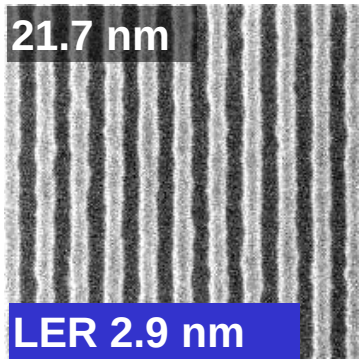
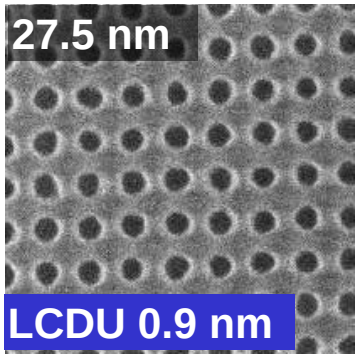
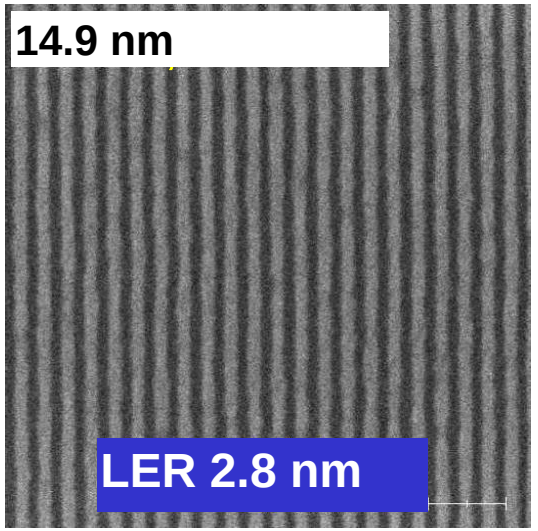
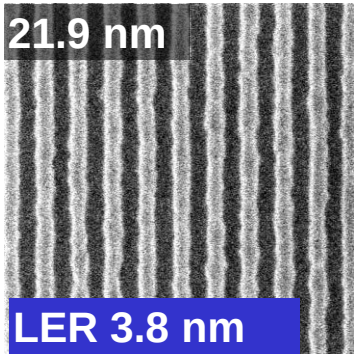
- Special thanks for the EUVL experiments.

Thank you for your kind attention !!

Lithography performances of Fujifilm EUV resists

NXE :3100 data, dipole illumination

LBNL MET data, Pseudo PSM

	22nm L/S	28nm CH	15nm L/S
FEVS-P1507D	 E = 20.5 mJ/cm^2	 E = 26.2 mJ/cm^2	 E = 33.6 mJ/cm^2 FEVS -P1507D4
FEVS-P1507D2	 E = 12.4 mJ/cm^2	No data	

Application to 22 nm L/S, 28 nm C/H processes
Ultimate resolution down to 15 nm L/S