FUJIFILM
Value from Innovation

NEVER STOP

藤森　亨　TORU FUJIMORI

2020. 11. 6

FUJIFILM Corporation

Electronic Materials Research Laboratories
R&D Management Headquarters

FUJIFILM
Value from Innovation

NEVER STOP

How to reduce the stochastic issue in EUV lithography ?

藤森　亨　**TORU FUJIMORI**

2020. 11. 6

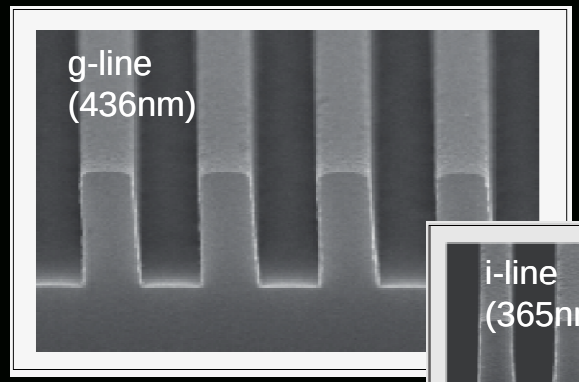
FUJIFILM Corporation

Electronic Materials Research Laboratories
R&D Management Headquarters

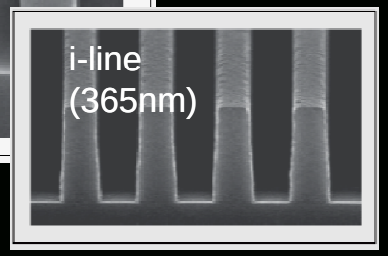
The Pattern shrinkage history

FUJIFILM
Value from Innovation

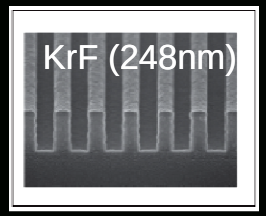
Pattern shrinkage has been driven by shorter exposure wave length.



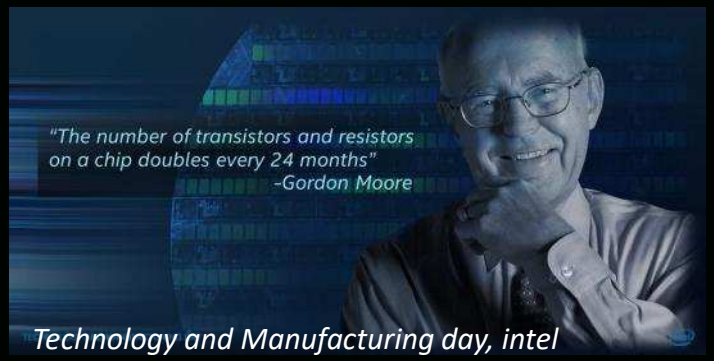
CD = 500nm



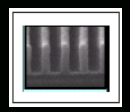
350 nm



150 nm



ArF
(193nm)



90nm

ArFi
(134nm
eq.)

40nm

EUV
(13.5nm)

15nm

Pattern Shrinkage : " Never Stop "

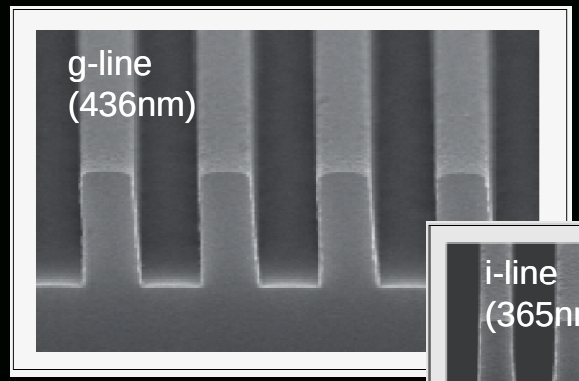
Resist materials development : " Never Stop "

NEVER STOP

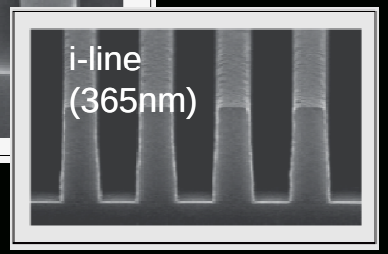
The Pattern shrinkage history

FUJIFILM
Value from Innovation

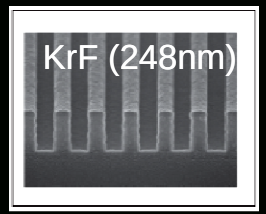
Pattern shrinkage has been driven by shorter exposure wave length.



CD = 500nm

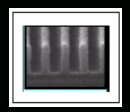


350 nm



150 nm

ArF
(193nm)



90nm

ArFi
(134nm
eq.)

40nm

EUV
(13.5nm)

15nm

EUV lithography

Too difficult to apply for manufacturing for a long time

Pattern Shrinkage : " Never Stop "

Resist materials development : " Never Stop "

NEVER STOP

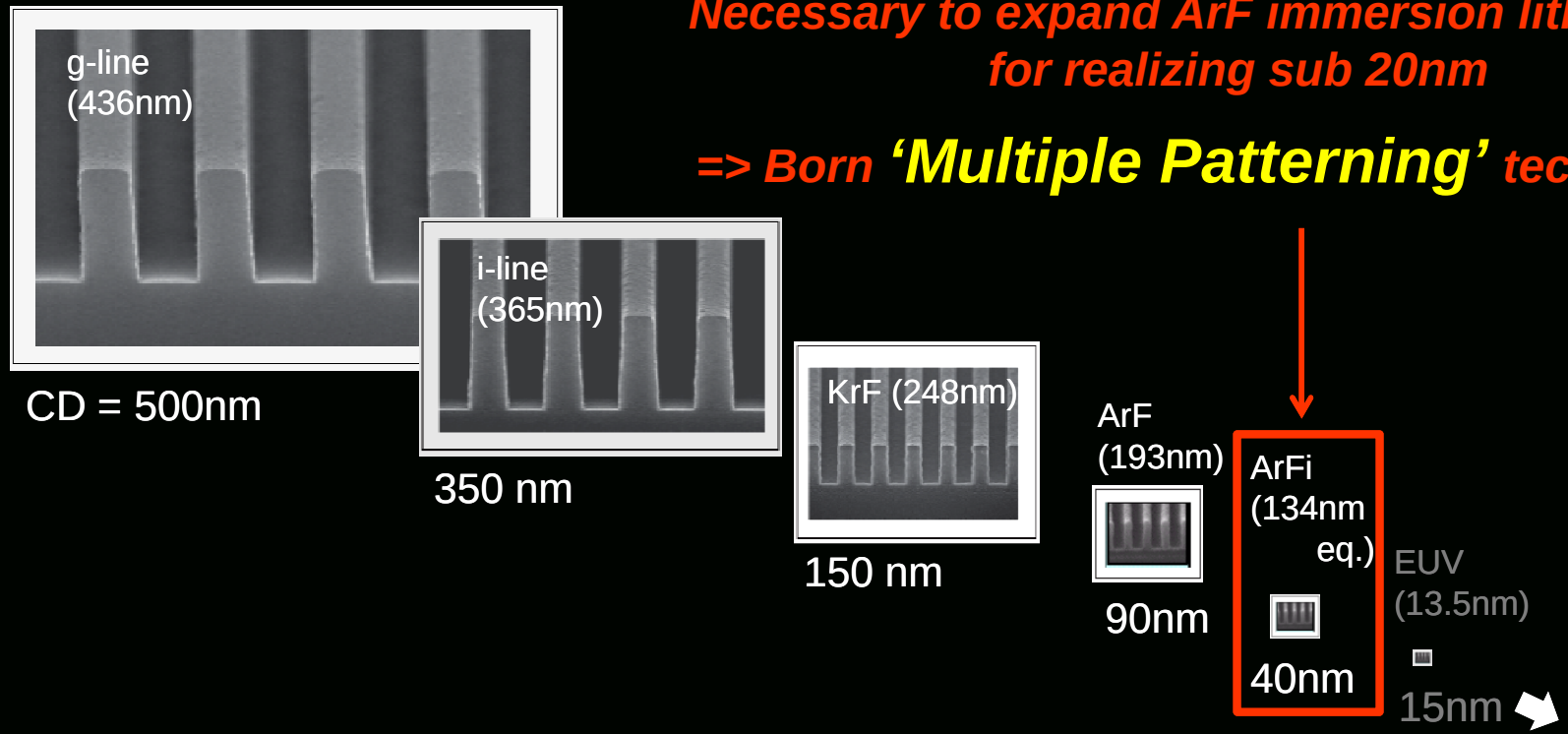
The Pattern shrinkage history

FUJIFILM
Value from Innovation

Pattern shrinkage has been driven by shorter exposure wave length.

Necessary to expand ArF immersion lithography for realizing sub 20nm

*=> Born **'Multiple Patterning'** technology*



Pattern Shrinkage : " Never Stop "

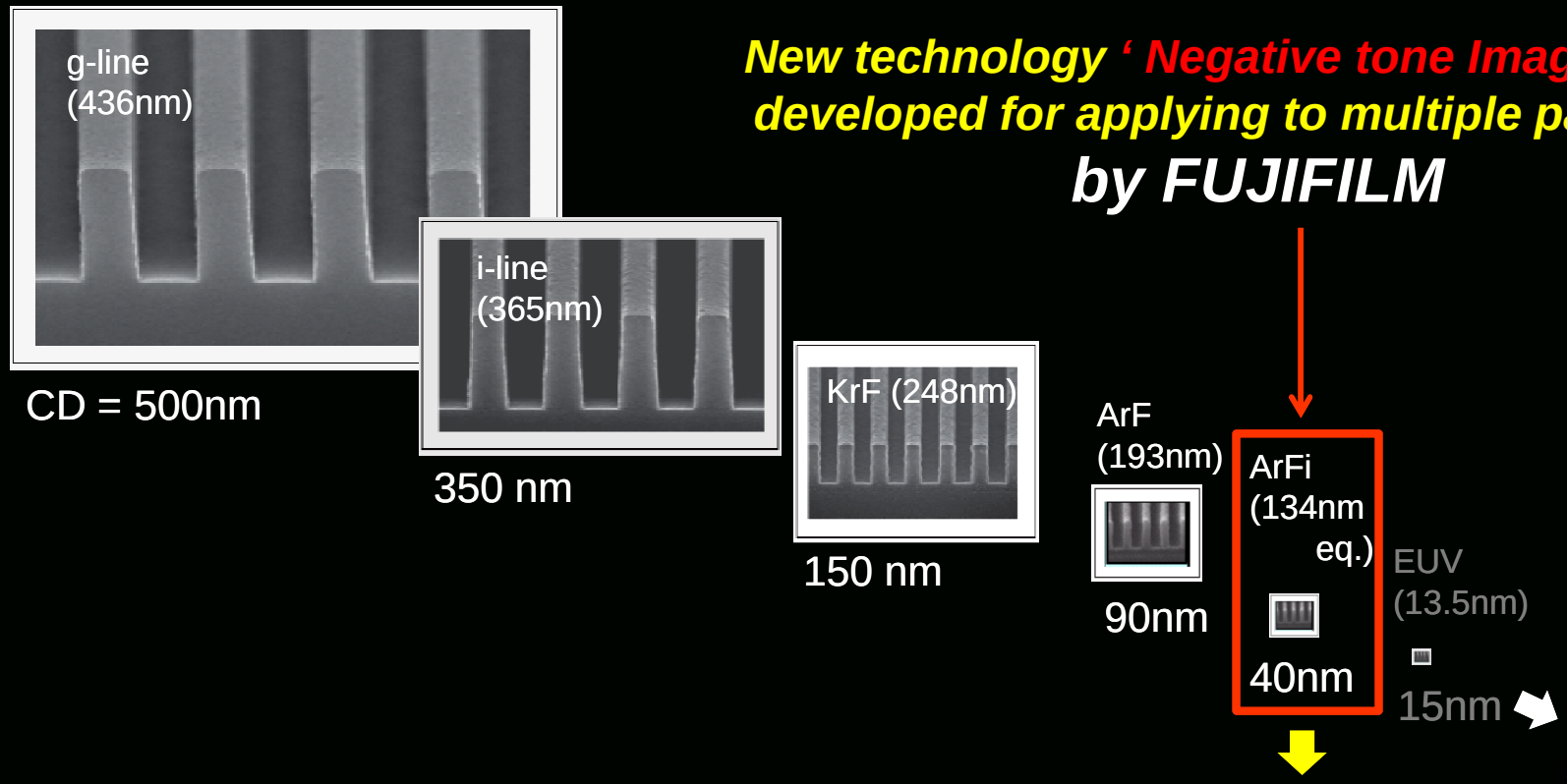
Resist materials development : " Never Stop "

NEVER STOP

The Pattern shrinkage history

FUJIFILM
Value from Innovation

Pattern shrinkage has been driven by shorter exposure wave length.



New technology ' Negative tone Imaging ' was developed for applying to multiple patterning by FUJIFILM

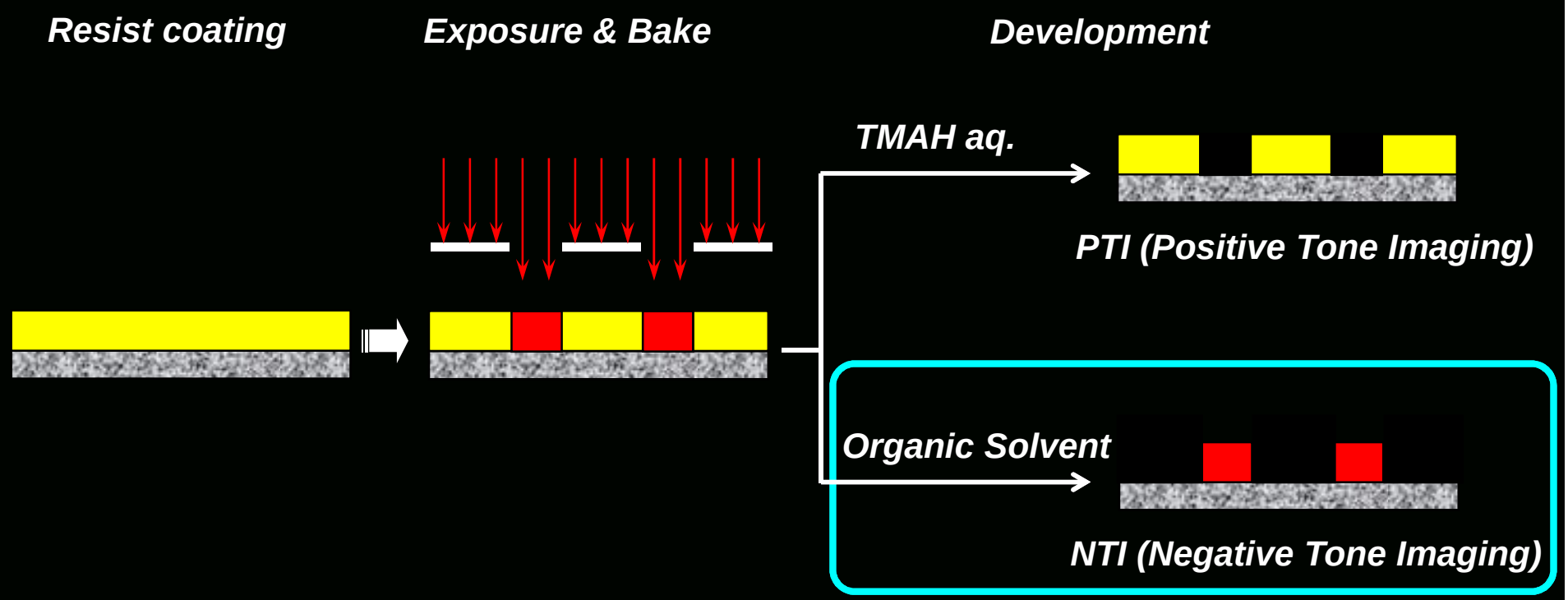
Resist materials development : " Never Stop "

NEVER STOP

The process flow of the lithography

FUJIFILM
Value from Innovation

PTI (Positive Tone Imaging) & NTI (Negative Tone Imaging)

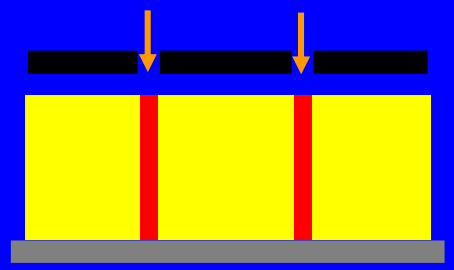


Resist materials development : " Never Stop "

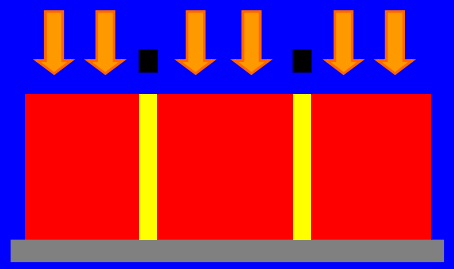
NEVER STOP

Theory of Optical Contrast Utilization (PTI vs NTI)

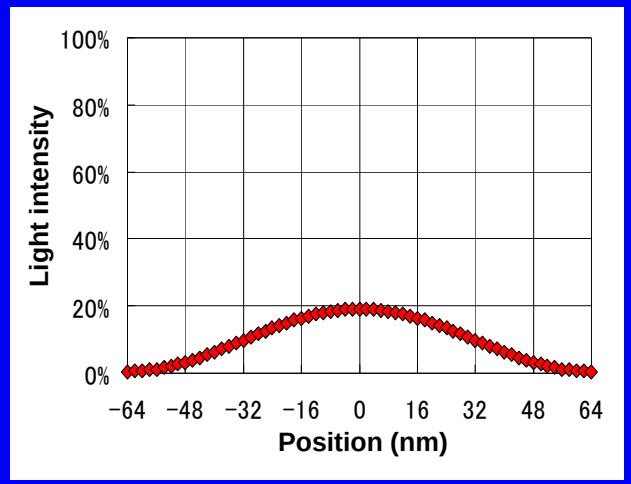
FUJIFILM
Value from Innovation

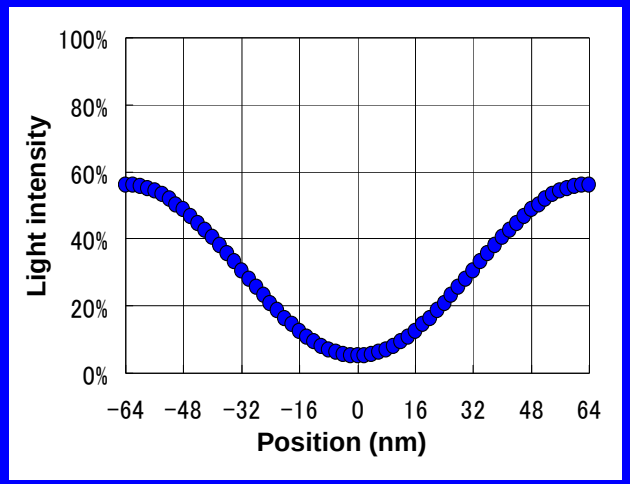


Prepare Trench pattern
by PTI



Prepare Trench pattern
by NTI





Trench pattern 32nm 1:3

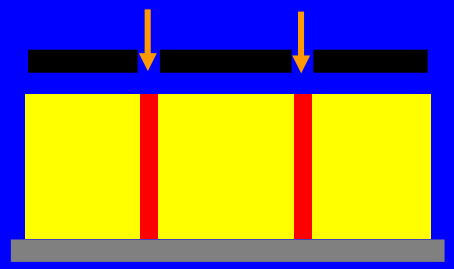
High resolution can be expected by strong contrast with NTI process.

Resist materials development : " Never Stop "

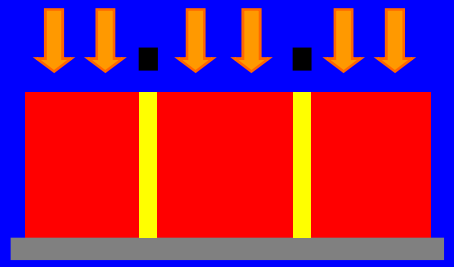
NEVER STOP

The resulting patterning comparison (PTI vs NTI)

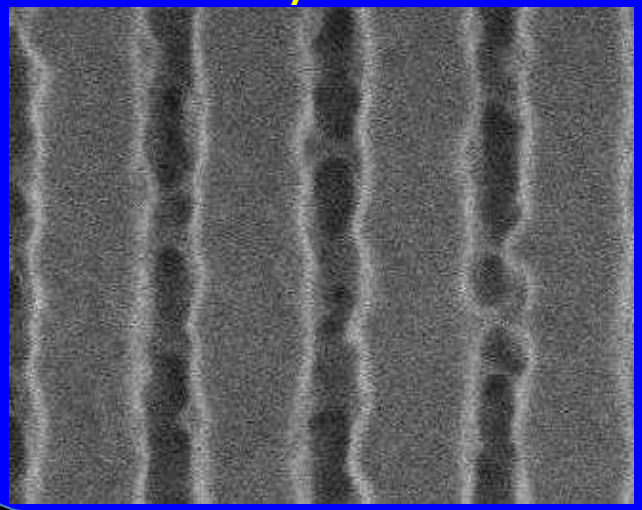
FUJIFILM
Value from Innovation

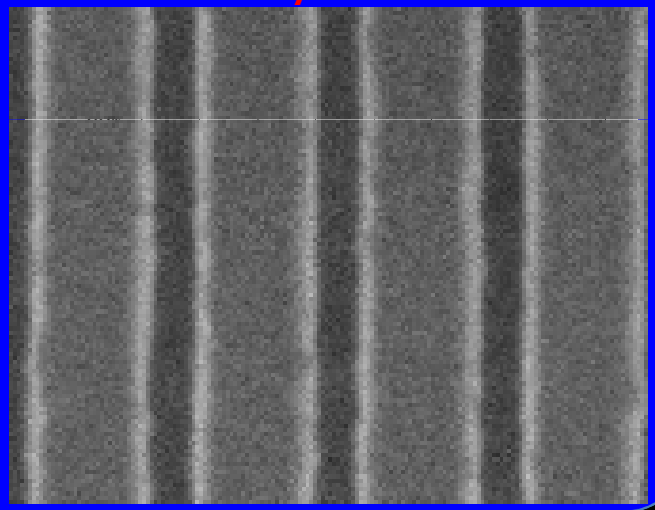


Prepare Trench pattern
by PTI



Prepare Trench pattern
by NTI





Trench pattern 32nm 1:3

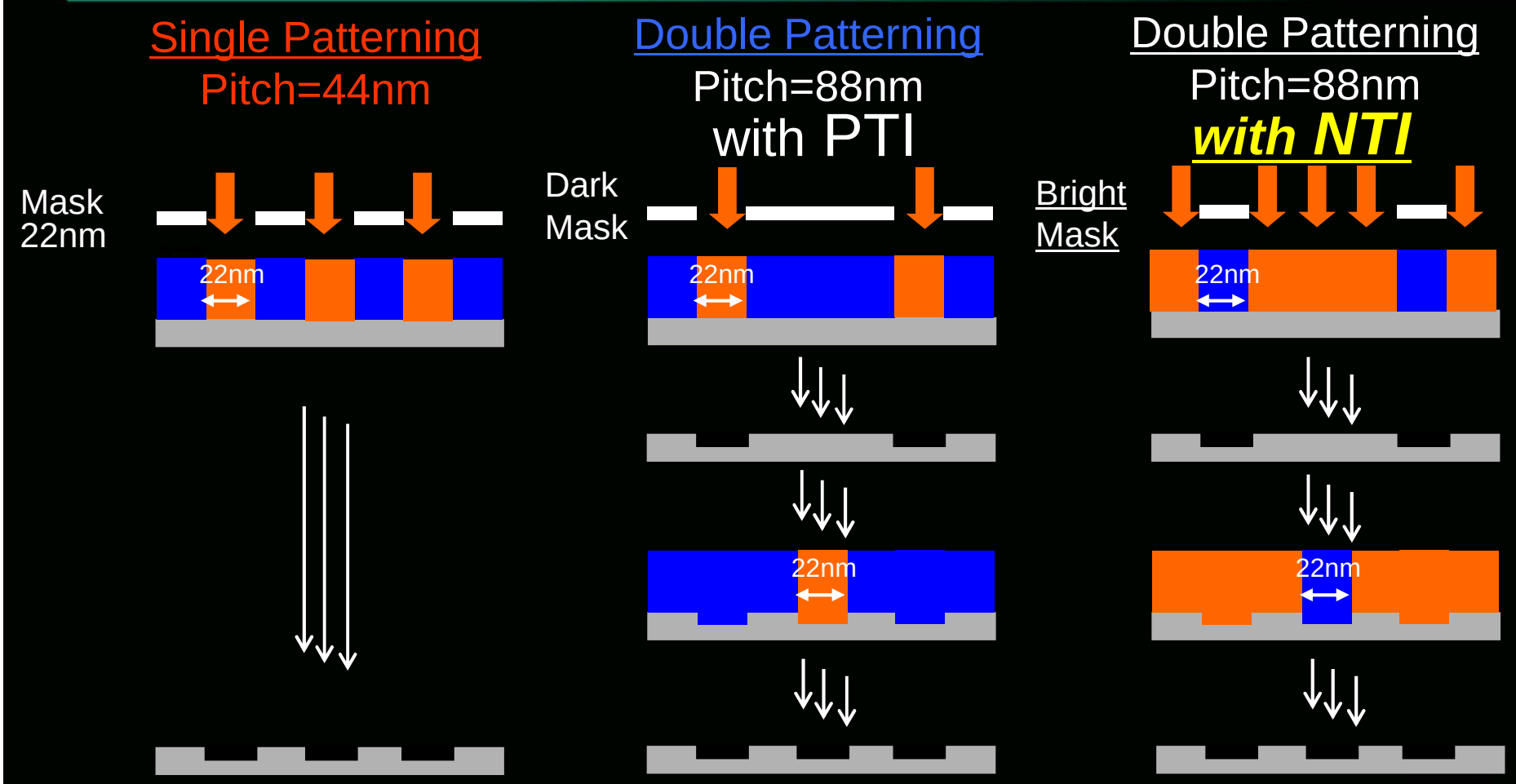
NTI process observed brilliant resolution,
useful for multiple patterning !!

Resist materials development : " Never Stop "

NEVER STOP

What is NTI useful for ? Ex) Prepare P44nm LS (1:1)

FUJIFILM
Value from Innovation



Resist materials development : " Never Stop "

NEVER STOP

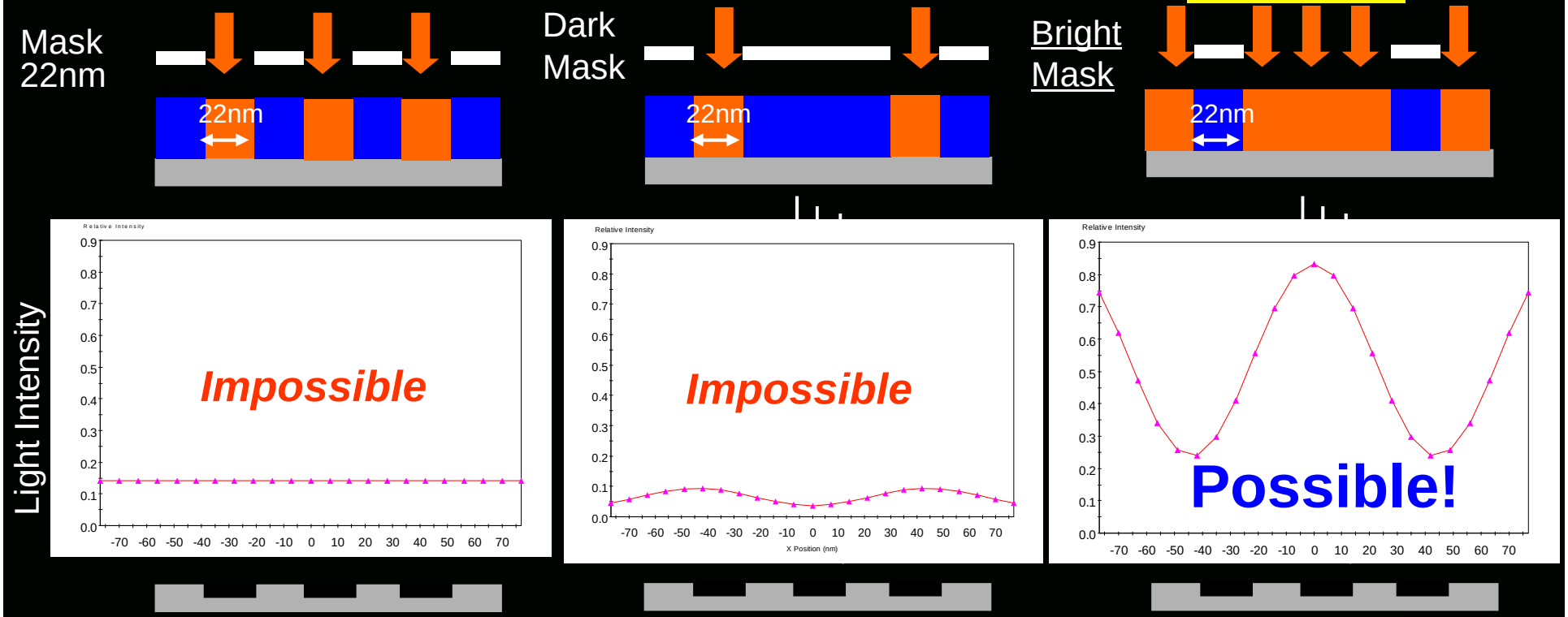
What is NTI useful for ? Ex) Prepare P44nm LS (1:1)

FUJIFILM
Value from Innovation

Single Patterning
Pitch=44nm

Double Patterning
Pitch=88nm
with PTI

Double Patterning
Pitch=88nm
with NTI



Resist materials development : " Never Stop "

NEVER STOP

What is NTI useful for ? EX. Double patterning.

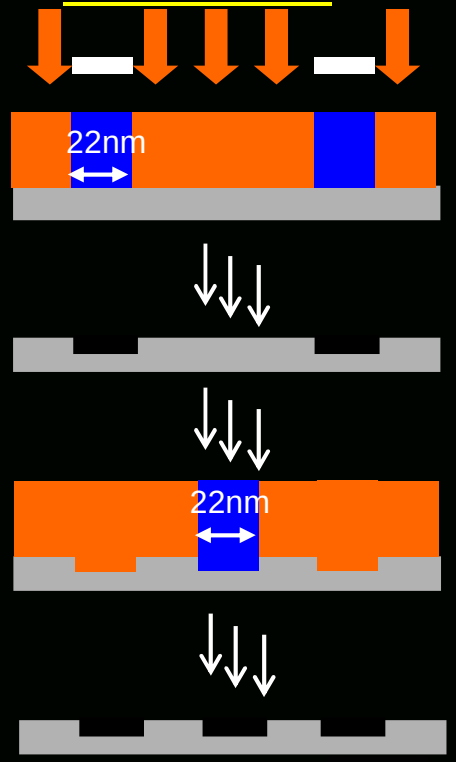
FUJIFILM
Value from Innovation

Only '***Double patterning with NTI '***
can be observed brilliant patterns !

Of course,
can be applied to ***multiple patterning*** !

Also,
' Developer ' is very important.
Has to be used ' ***Ultra pure solvent*** '.

Double Patterning
Pitch=88nm
with NTI



History of EUV lithography

FUJIFILM
Value from Innovation

In 2018

Qualcomm
released SD 855 !

Impress Watch

7nm design rule
(Already installed to smart phone in 2019)

By using ArFi multi-patterning w/o EUV litho
*Lots of **NTI process** were used.*

However,
for manufacturing of next generation chips,

*it necessary to use **EUV lithography !***

Resist materials development : " Never Stop "

NEVER STOP

History of EUV lithography

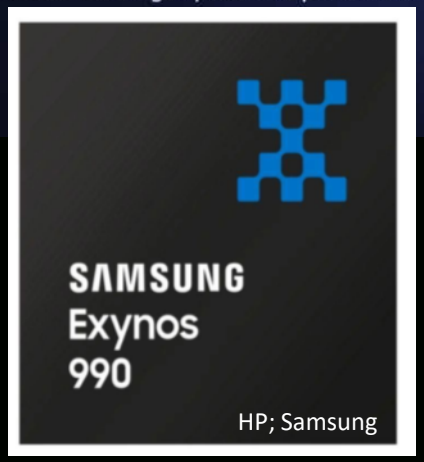
FUJIFILM
Value from Innovation

Finally, EUV lithography generation has come.

In 2019 7nm+ design rule was applied to HVM by using EUV lithography patterning.

Qualcomm
New chip release !

K-tai. watch. impress



Already installed to 5G smart phone in 2020

Resist materials development : " Never Stop "

NEVER STOP

History of EUV lithography

FUJIFILM
Value from Innovation

The first paper of EUV lithography - by Prof. Kinoshita -

Anthony Yen, EUV lithography: From the very Beginning to the eve of manufacturing (SPIE 2016)

National Project in Japan
↓
1996
↓ **Selete**
2011
↓ **EIDEC**
2019 **Over 23years !**

Waiting for EUV lithography
for a lo----------ng time.

Finally, *EUV generation has come*
in 2019, 令和元年(*Reiwa 1*) in Japan.

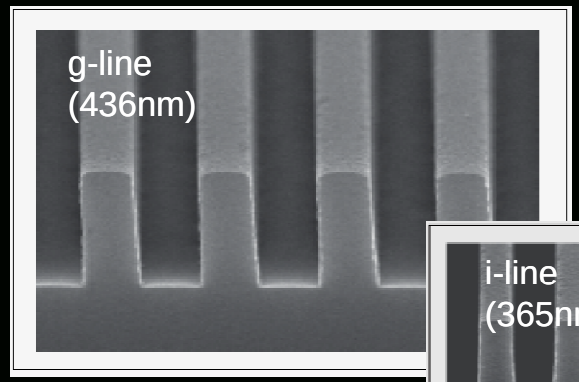
Resist materials development : " Never Stop "

NEVER STOP

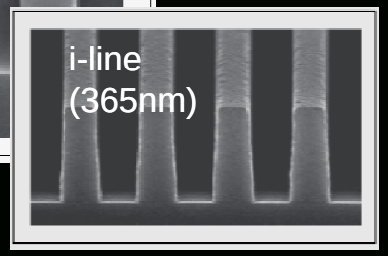
The Pattern shrinkage history

FUJIFILM
Value from Innovation

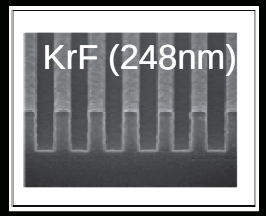
Pattern shrinkage has been driven by shorter exposure wave length.



CD = 500nm

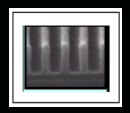


350 nm



150 nm

ArF
(193nm)



90nm

ArFi
(134nm
eq.)

40nm

EUV
(13.5nm)

15nm

EUV lithography

Keep going to improve continuously

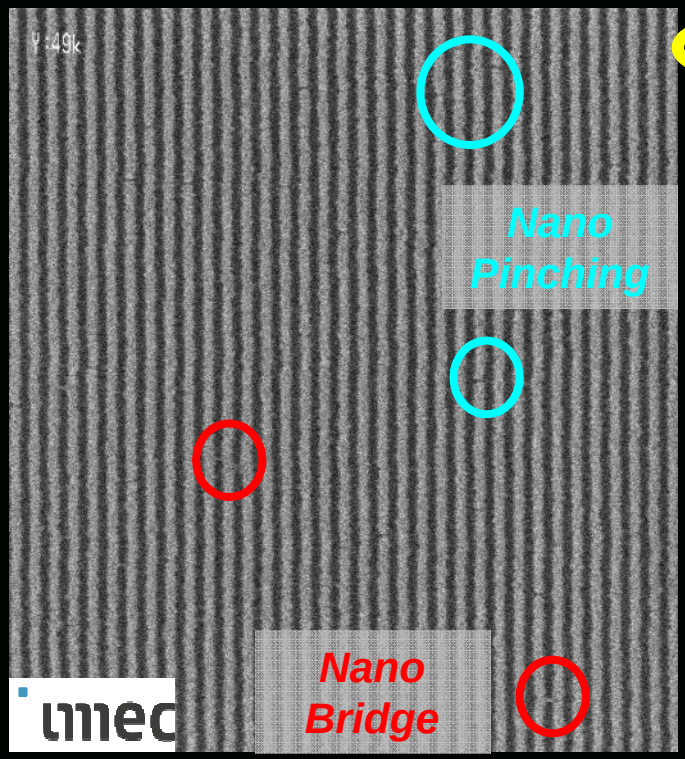
Pattern Shrinkage : " Never Stop "

Resist materials development : " Never Stop "

NEVER STOP

Challenging of EUV resist

FUJIFILM
Value from Innovation



HP13nm
Eopt = 42 mJ/cm^2
LWR = 5.3 nm

The resolution looks good enough.

However,
"Nano-Bridge" and "Nano-Pinching" were observed.

=> Becomes an obstacle for HVM.

How to reduce the stochastic factor ?

Resist materials development : " Never Stop "

NEVER STOP

What is the stochastic ?

FUJIFILM
Value from Innovation

Have you ever heard "stochastic" ?

What is the stochastic issues ?

Why now ?? No issues before ?

Basically, it means...

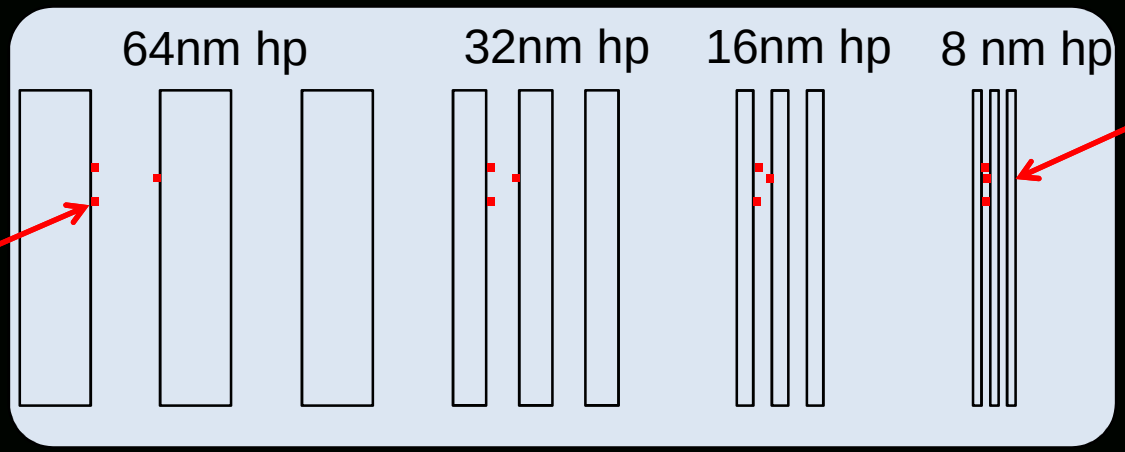
Random

随机

隨機

Influence of pattern size shrinkage !

Example)



6nm x 6nm defect

No impact

6nm x 6nm defect

Huge impact

Resist materials development : " Never Stop "

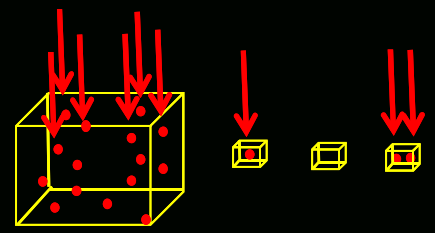
NEVER STOP

Improvement of EUV resist performance

FUJIFILM
Value from Innovation

How to improve the stochastic issues?

Focus on 2 major Stochastic issues



1. **Photon stochastic** (photon shot noise)
   (Cause : light source)
   Poor photon number.
   => The resist materials can help it.
   Introduce the function of 'catch more photon'.
2. **Chemical stochastic**
   (Cause : resist)
   The materials location randomness in the film.
   The reaction randomness in the film.
   => The ***functionalized materials*** are effective.

Resist materials development : " Never Stop "

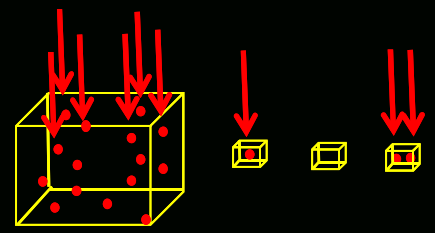
NEVER STOP

Improvement of EUV resist performance

FUJIFILM
Value from Innovation

How to improve the stochastic issues?

Focus on 2 major Stochastic issues



1. **Photon stochastic** (photon shot noise)
   (Cause : light source)
   Poor photon number.
   => The resist materials can help it.
   Introduce the function of 'catch more photon'.
2. **Chemical stochastic**
   (Cause : resist)
   The materials location randomness in the film.
   The reaction randomness in the film.
   => The ***functionalized materials*** are effective.

Resist materials development : " Never Stop "

NEVER STOP

Improvement of EUV resist performance

FUJIFILM
Value from Innovation

Reaction mechanism of CAR with EUV exposure

1st step

Catch the light

2nd step

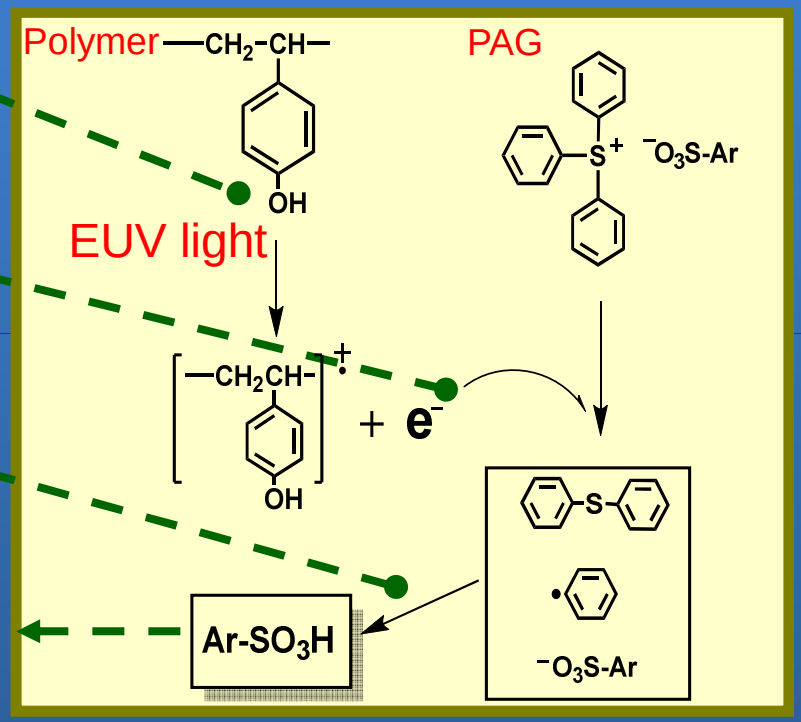
Generate the secondary electron

3rd step

Generate the acid

4th step

React with acid labile group



T. Kozawa *et al.*, *J. Vac. Sci. Technol. B, 22, 3489* (2004)

1st /2nd step

Different **from previous litho.**

1st step

(Catch the light)

Very important to realize EUV lithography.

Resist materials development : " Never Stop "

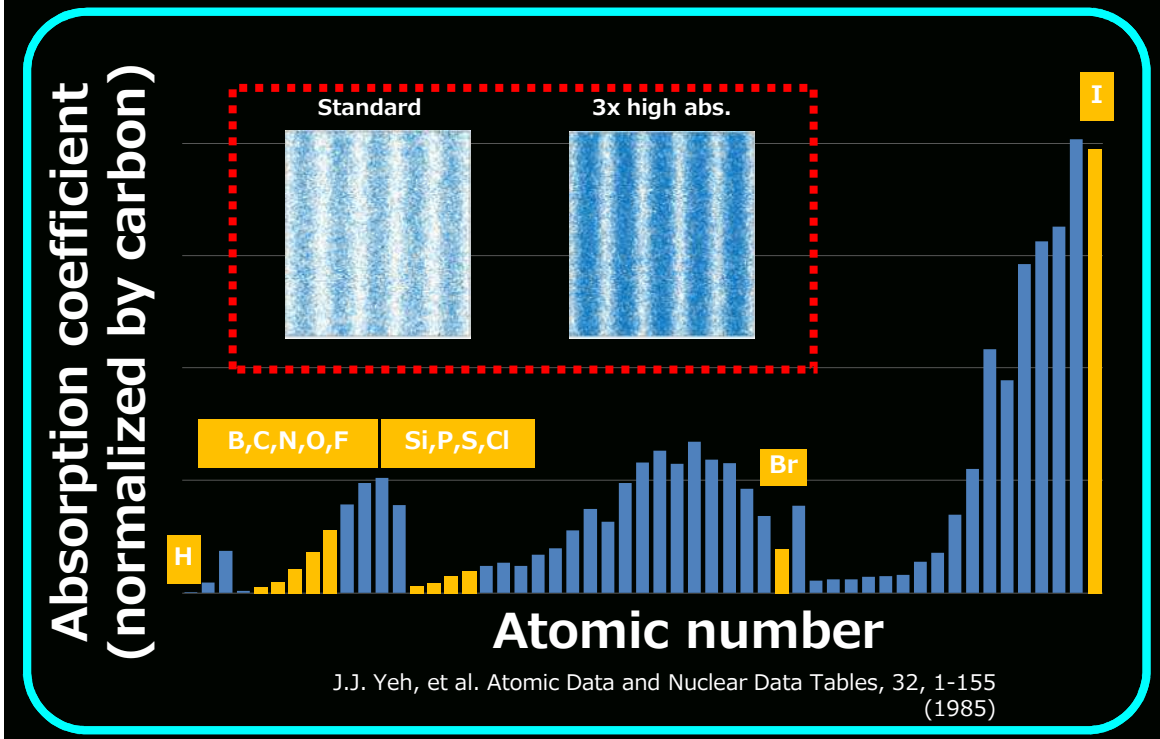
NEVER STOP

Organic high-EUV absorption CAR

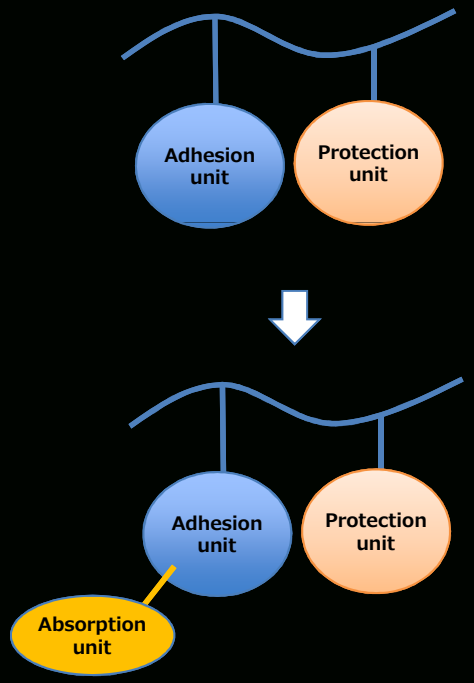
FUJIFILM
Value from Innovation

For realizing to catch the light more efficiency,

Designed ‘Organic high EUV absorption materials’.



J.J. Yeh, et al. Atomic Data and Nuclear Data Tables, 32, 1-155 (1985)



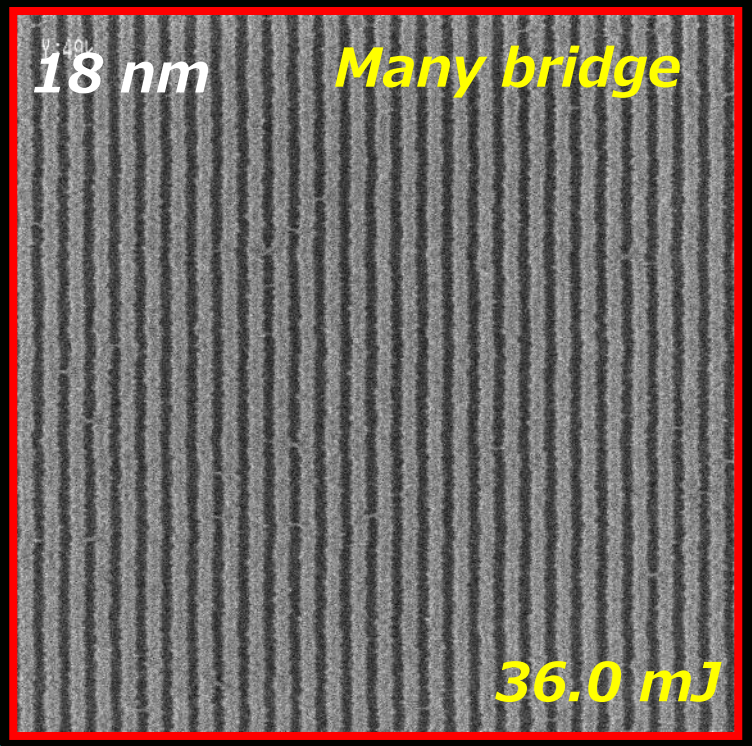
Resist materials development : “ Never Stop ”

NEVER STOP

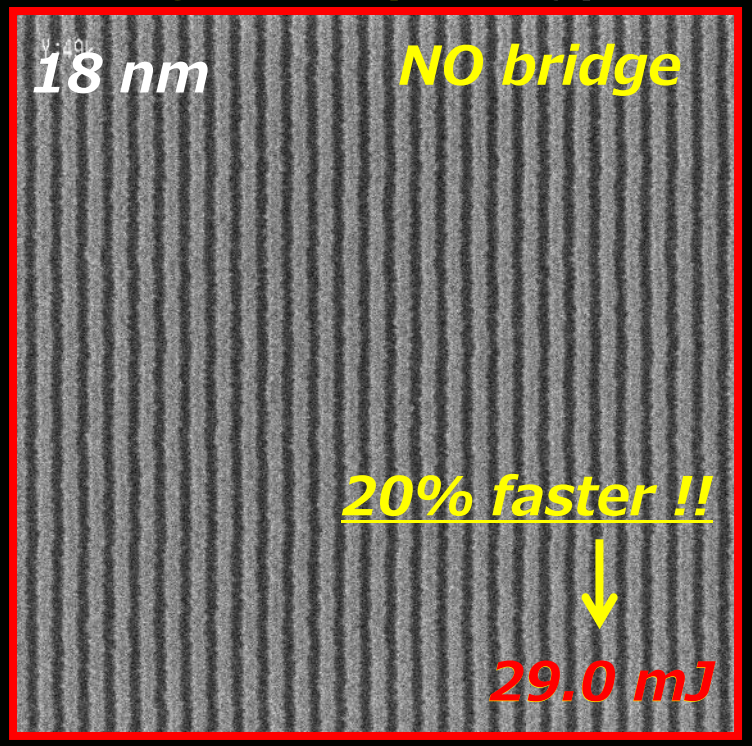
Organic high-EUV absorption CAR

FUJIFILM
Value from Innovation

Standard type



High absorption type



Excellent bridging performance with high sensitivity !!

Resist materials development : " Never Stop "

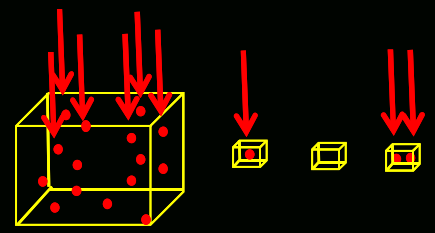
NEVER STOP

Improvement of EUV resist performance

FUJIFILM
Value from Innovation

How to improve the stochastic issues?

Focus on 2 major Stochastic issues



1. **Photon stochastic** (photon shot noise)
   (Cause : light source)
   Poor photon number.
   => The resist materials can help it.
   Introduce the function of 'catch more photon'.
2. **Chemical stochastic**
   (Cause : resist)
   The materials location randomness in the film.
   The reaction randomness in the film.
   => The ***functionalized materials*** are effective.

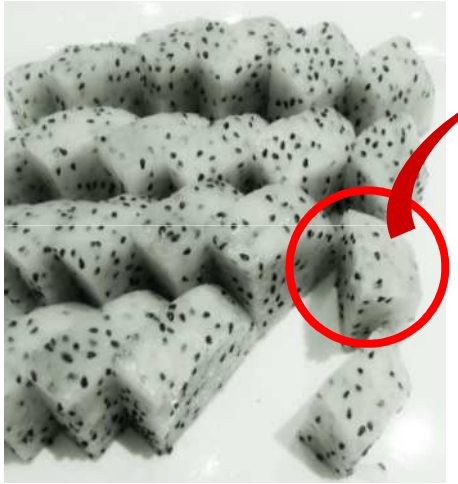
What is 'Chemical stochastic' ?

FUJIFILM
Value from Innovation

Chemical stochastic (Cause : resist, and/or nature phenomena)

The image of 'Chemical stochastic'
Example) ' Dragon fruits' 火龍果 ,火龙果

Seeds : Chemicals
Fruits : Polymer matrix



Each peace has *own locality* of the seeds.

***The seeds has locality* in one peace.**

Nobody can control the position of the seeds.

Resist materials development : " Never Stop "

NEVER STOP

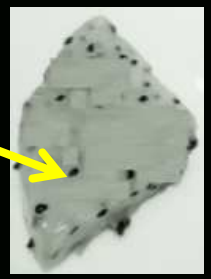
Fluctuation of quantum efficiency

FUJIFILM
Value from Innovation

One of the famous method to reduce 'Chemical stochastic'.
=> ***Higher PAG loading*** effect.

< Usual PAG loading >

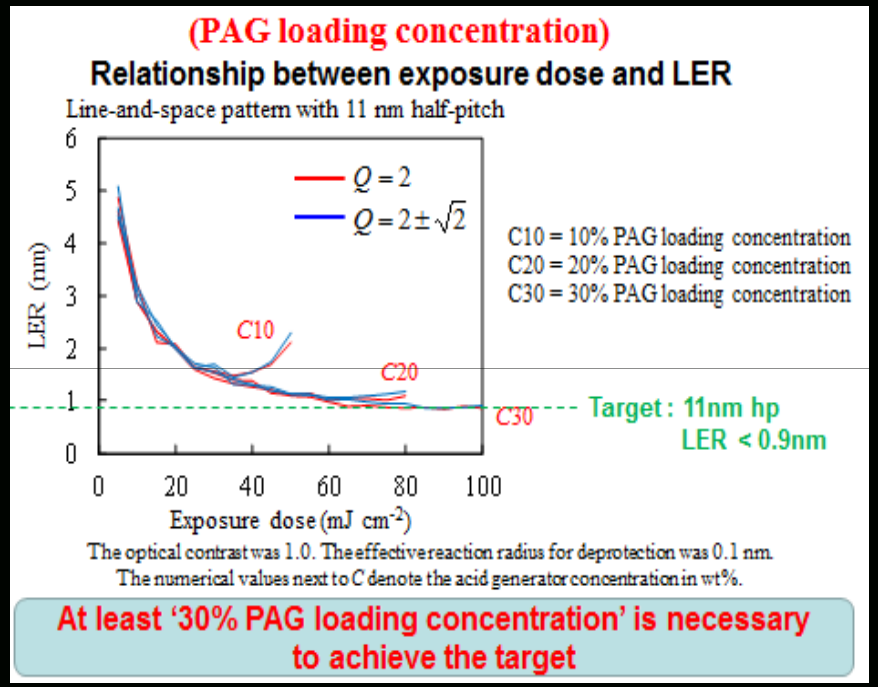
Lots of locality part



< Higher PAG loading >

Better uniformity

Higher chance to generate acids.
Higher chance to react.



T. Kozawa et al., simulation study with EIDEC.

Improve 'Chemical stochastic' !

Expected Excellent LER !!

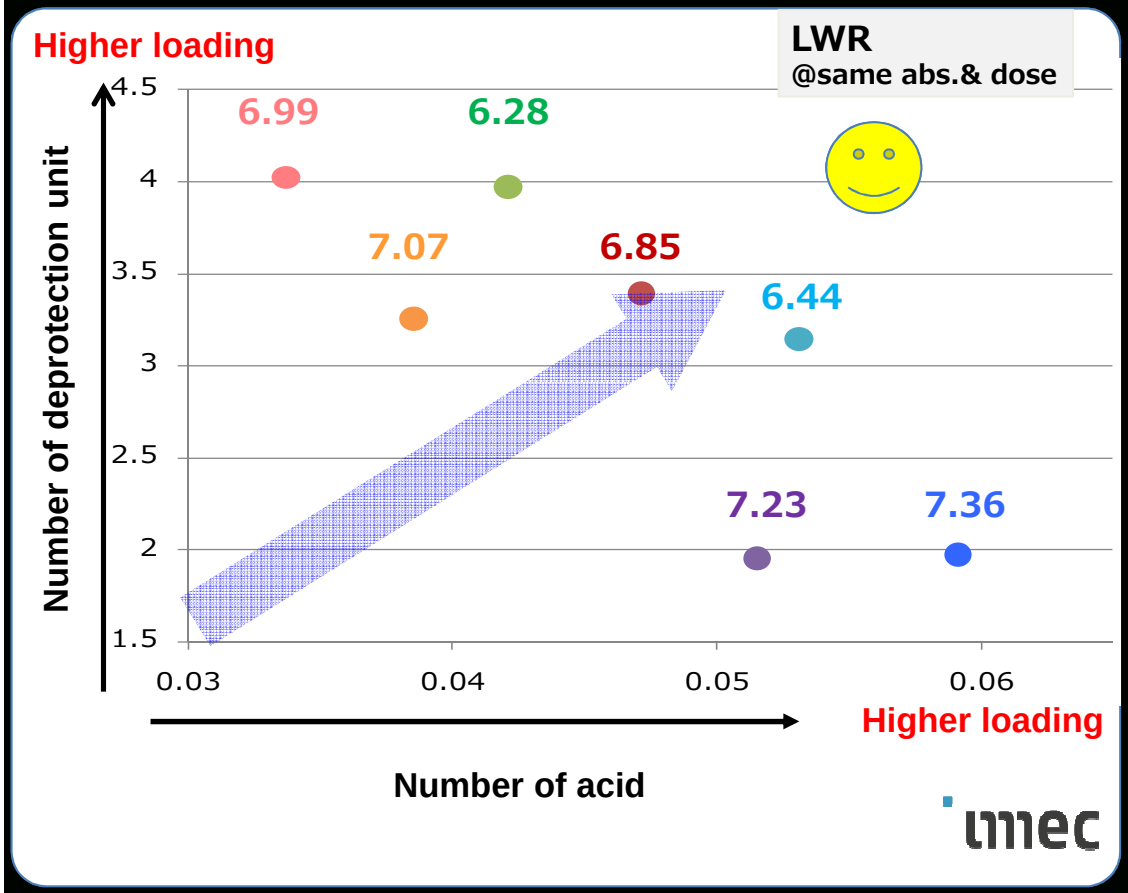
Resist materials development : " Never Stop "

NEVER STOP

Fluctuation of quantum efficiency

FUJIFILM
Value from Innovation

Higher loading mitigated stochastic effect.



PAG higher loading =>

Deprotection unit higher loading =>

Higher chance to generate acids.

Higher chance to react.

Improve 'Chemical stochastic' !

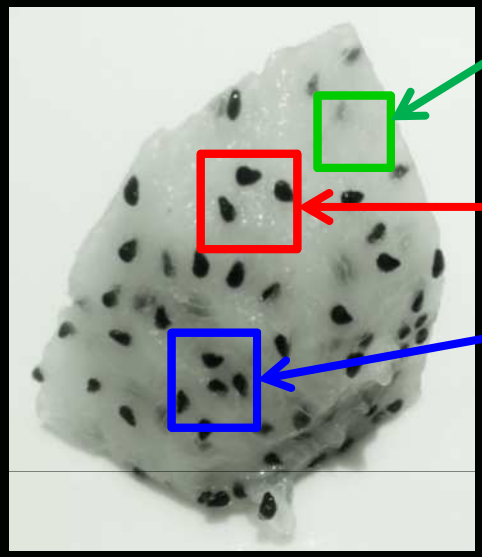
Indicated excellent LWR !!

Resist materials development : " Never Stop "

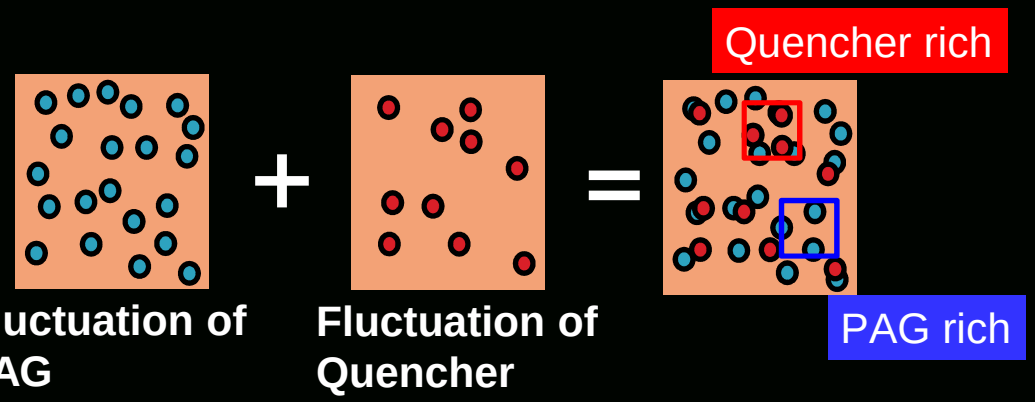
NEVER STOP

Further improvement of 'Chemical stochastic'

FUJIFILM
Value from Innovation



Current technology



The seeds has locality
in one peace.

Even, introduced *higher loading technology*, still remaining the fluctuation.

How to control of the position of seeds ? Possible ??

How to improve ???

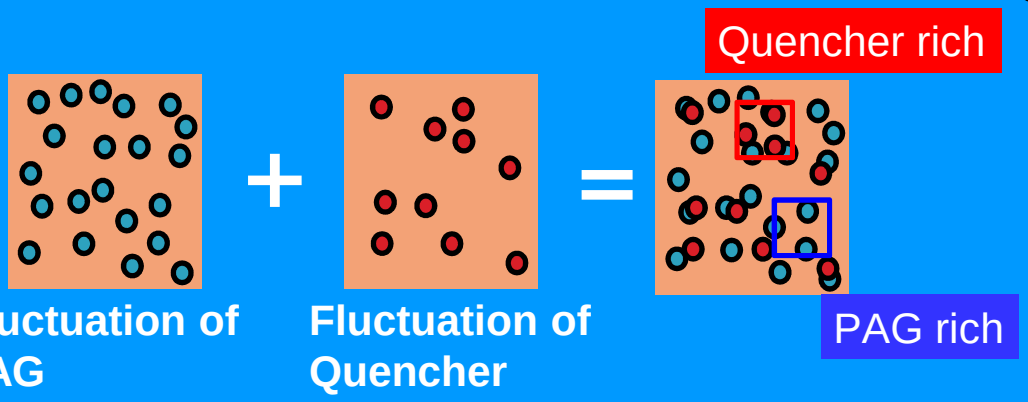
Resist materials development : " Never Stop "

NEVER STOP

Further improvement of 'Chemical stochastic'

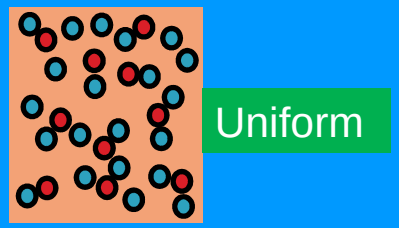
FUJIFILM
Value from Innovation

Current technology



New technology

Uniform disperse in the film by using the functionalized materials



Improve 'Chemical stochastic'.

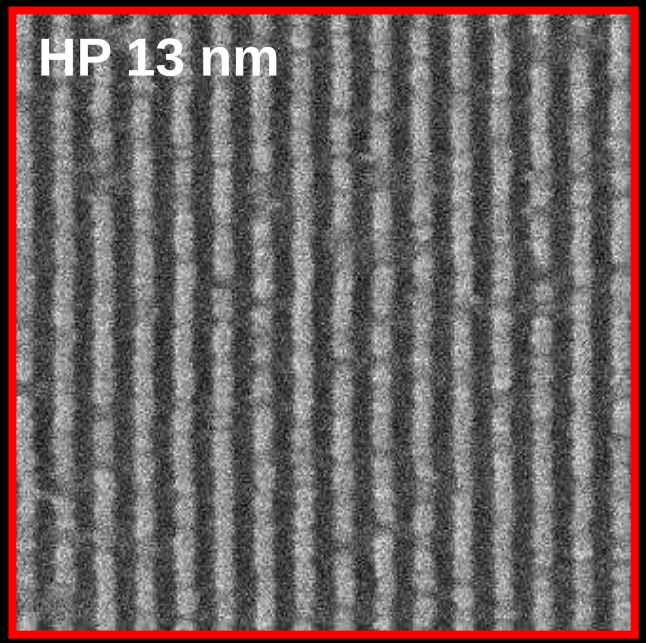
Resist materials development : " Never Stop "

NEVER STOP

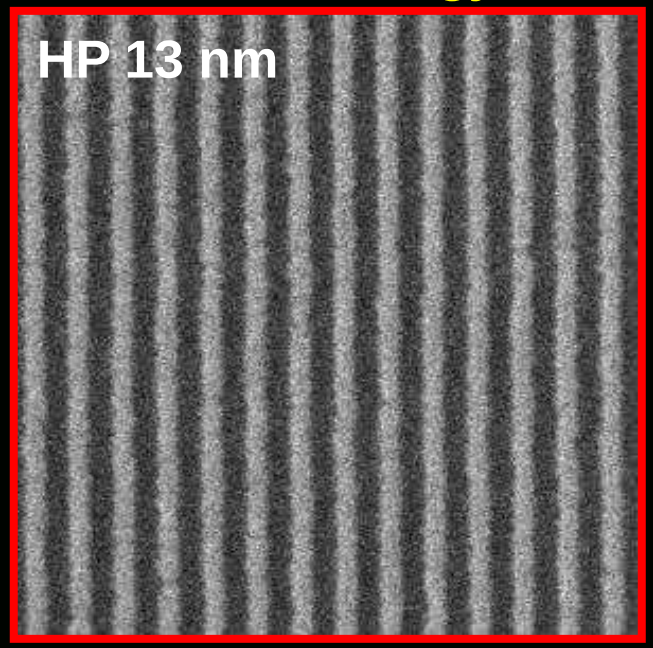
Further improvement of 'Chemical stochastic'

FUJIFILM
Value from Innovation

Current technology



New technology



New technology indicated brilliant performance !!

Resist materials development : " Never Stop "

NEVER STOP

Thank you for your kind attention !!

FUJIFILM
Value from Innovation

If you have any questions, comments,
or would like to communicate with me,
please let me know.

toru.fujimori@fujifilm.com

FUJIFILM
Value from Innovation
NEVER STOP