Impact of EUV mask structure on defect detectability of patterned mask inspection using Projection Electron Microscope

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Outline

- Introduction of EIDEC patterned mask inspection program
- Previous work (current tool performance and simulation results for EUV mask with Ru capped ML)
- Simulated inspection results
  - EUV mask with B_4C capped ML
  - EUV mask with B_4C buffered Ru capped ML
  - Etched ML EUV Mask
- The latest results
- Summary

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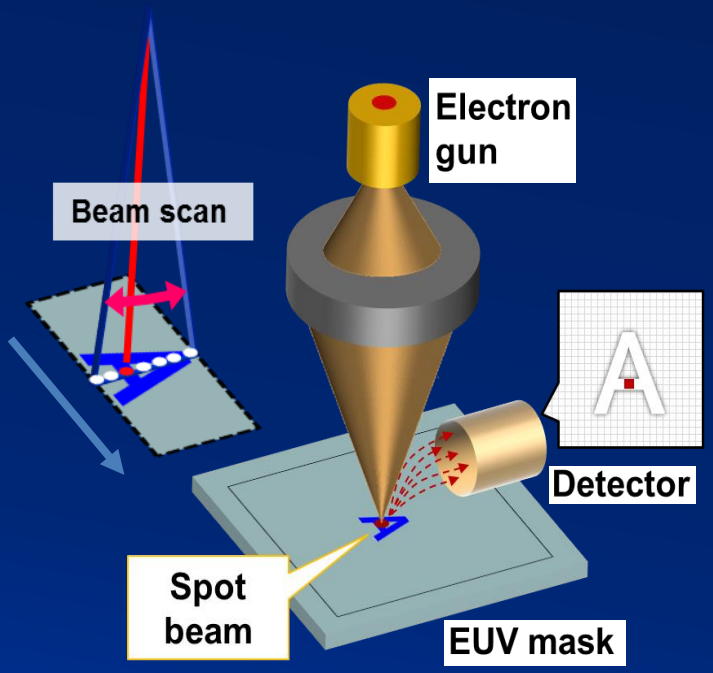
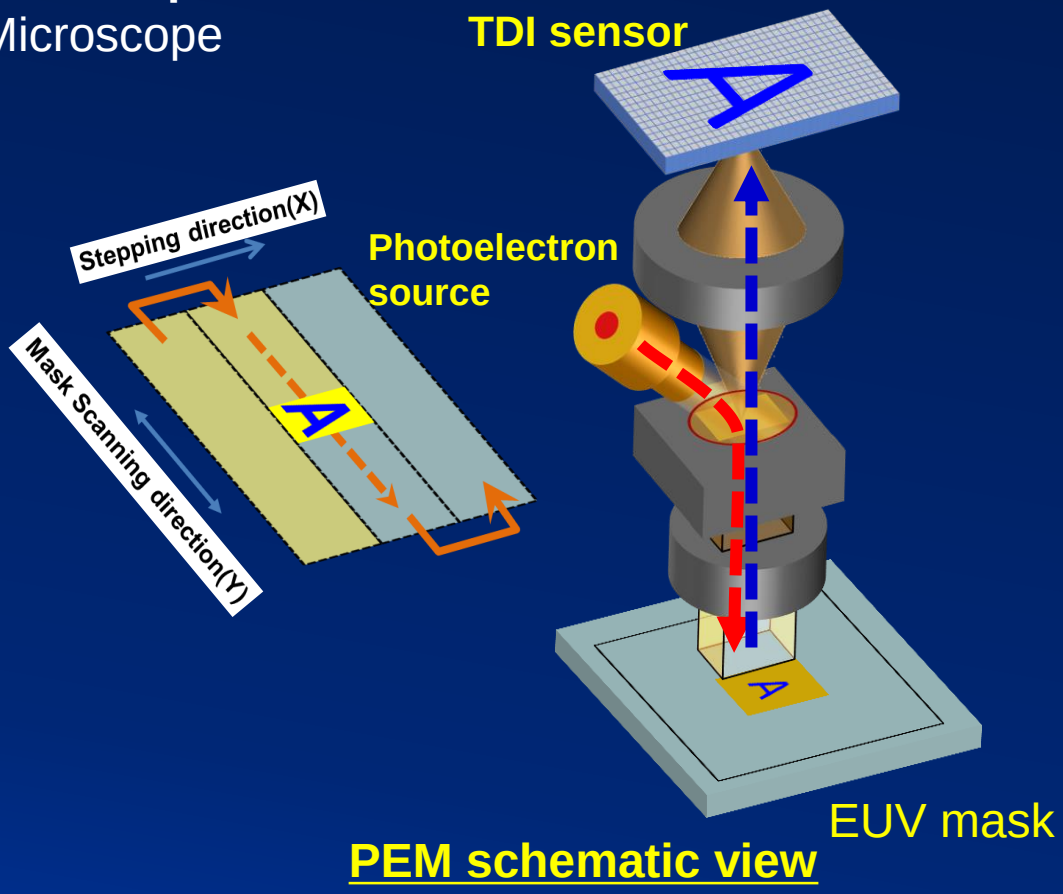
PEM for Patterned mask Inspection (PI)

PEM: Projection Electron Microscope
SEM: Scanning Electron Microscope



SEM schematic view

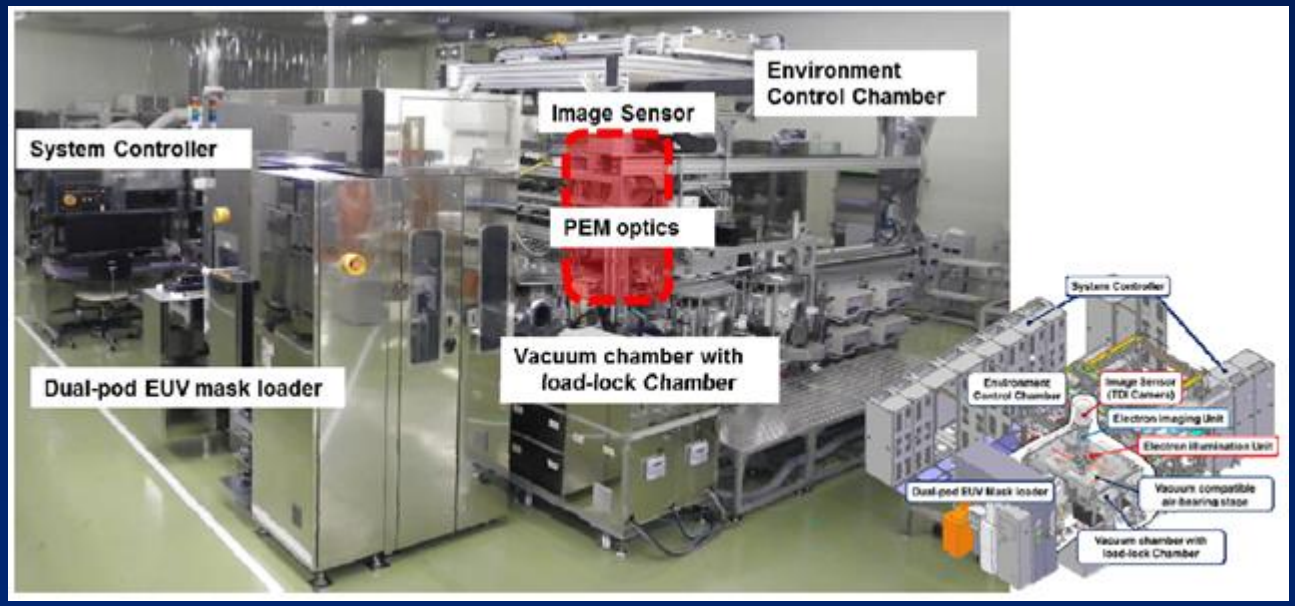


PEM schematic view

PEM probes sample mask with areal illumination

➡ Inspection throughput is drastically improved

Current status of our developed tool

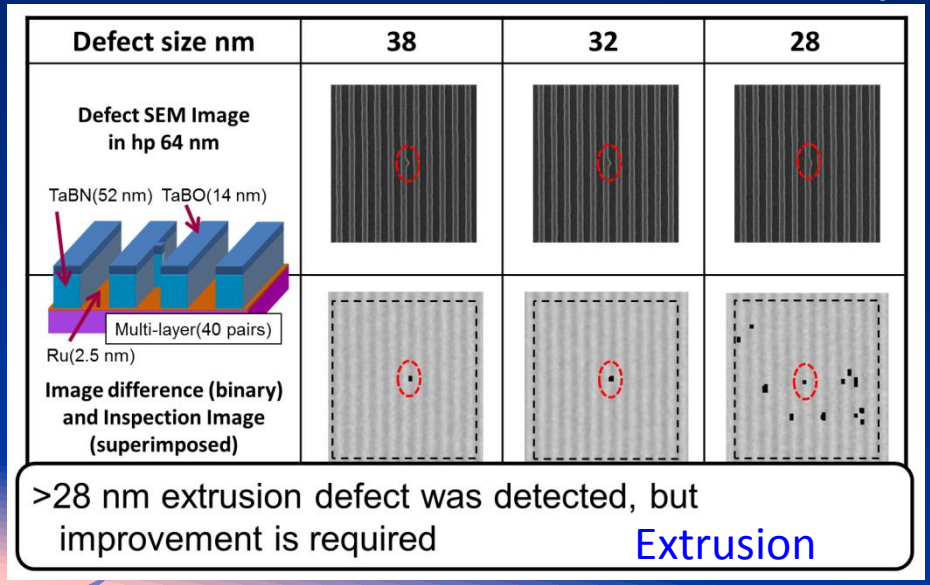


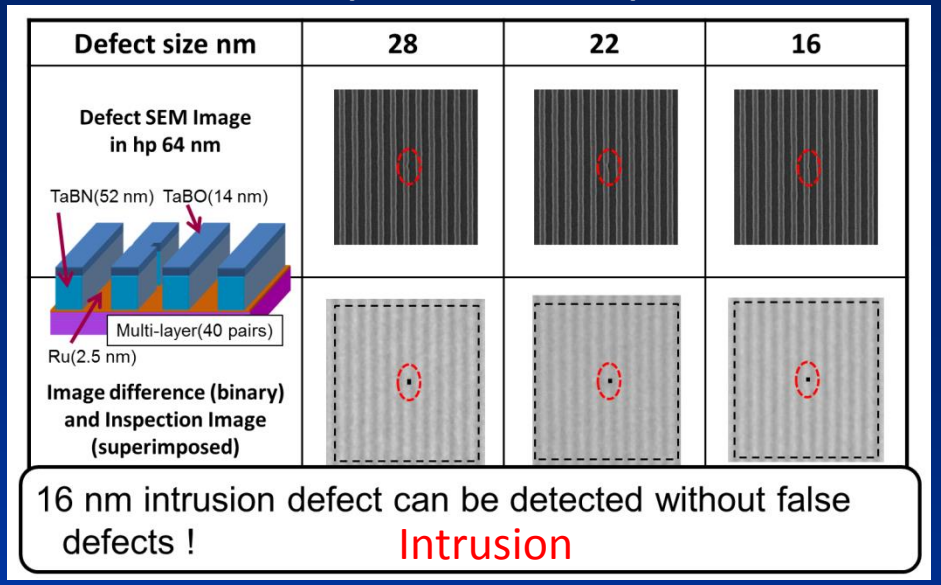
R. Hirano et al., Proc. of SPIE 8701, 870116 (2013)

Assembling is completed and image acquisition has been started.

R. Hirano, S. Iida et al. PMJ 2014

Tool performance of pattern inspection

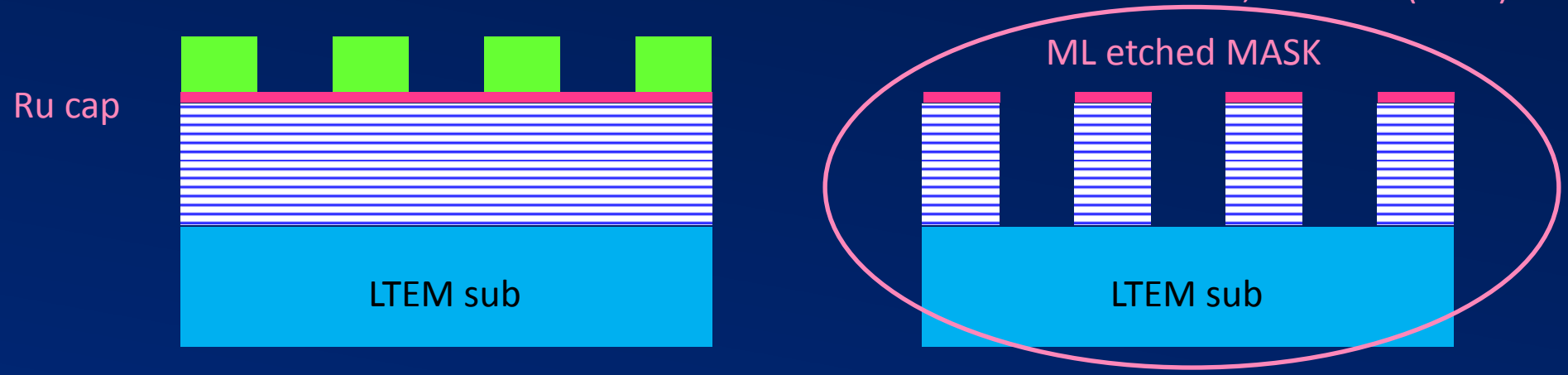




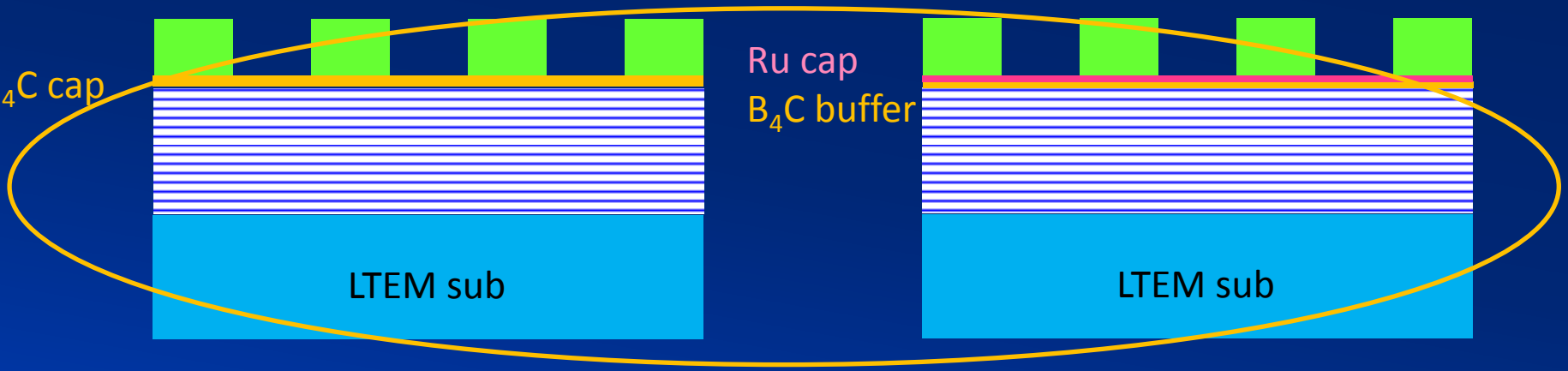
Several types of EUV mask structure proposed

High NA (TOSHIBA, DNP, Hanyang U)

Takai et al. Proc. SPIE 8880, 88802M (2013).



Inspection tools will be required to have high versatility.



High durability for cleaning (SEMATECH, Samsung)

I. Y. Jang et al. Proc. SPIE 9256, 92560I (2014).

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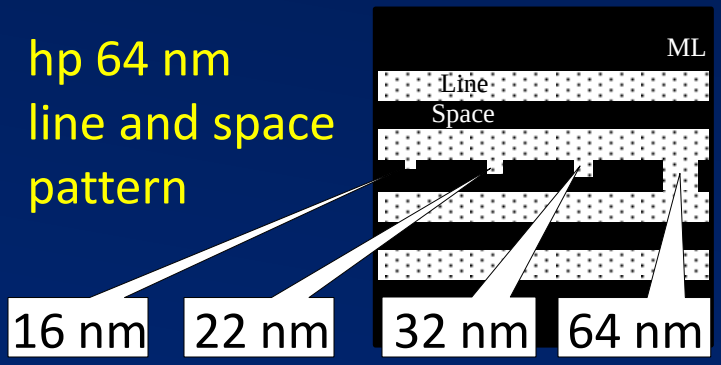
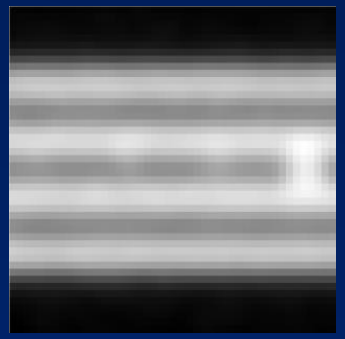
B_4C capped ML sample

Top view of sample for simulation

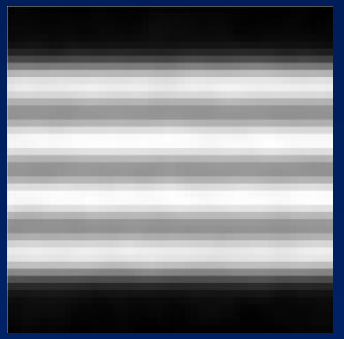
Simulated PEM image

hp 64 nm
line and space
pattern



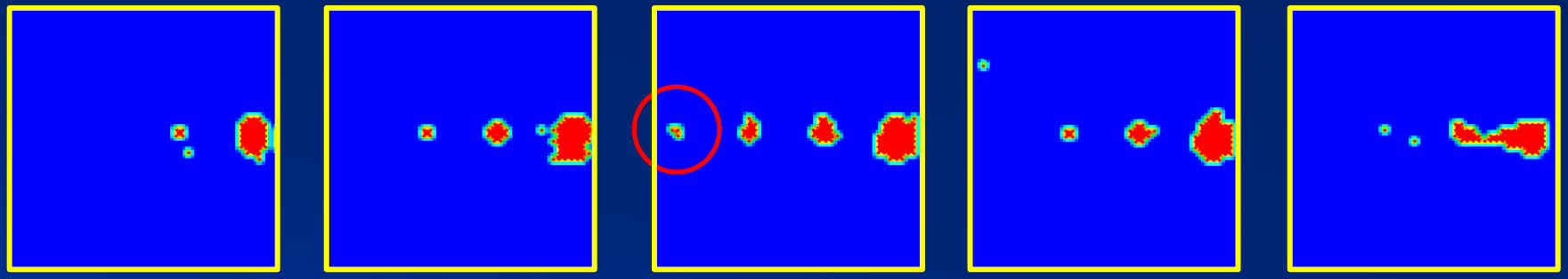


With defects



Reference

Extrusion defect



50 eV | 250 eV | 500 eV | 1 KeV | 3 keV

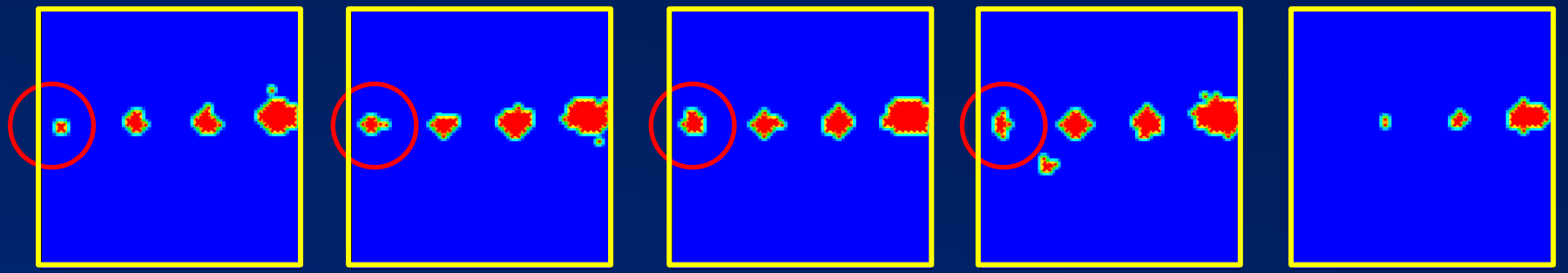
Difference image

Defect detection : $\frac{Defect\ signal\ intensity}{Back\ ground\ noise} = 10\ \sigma$

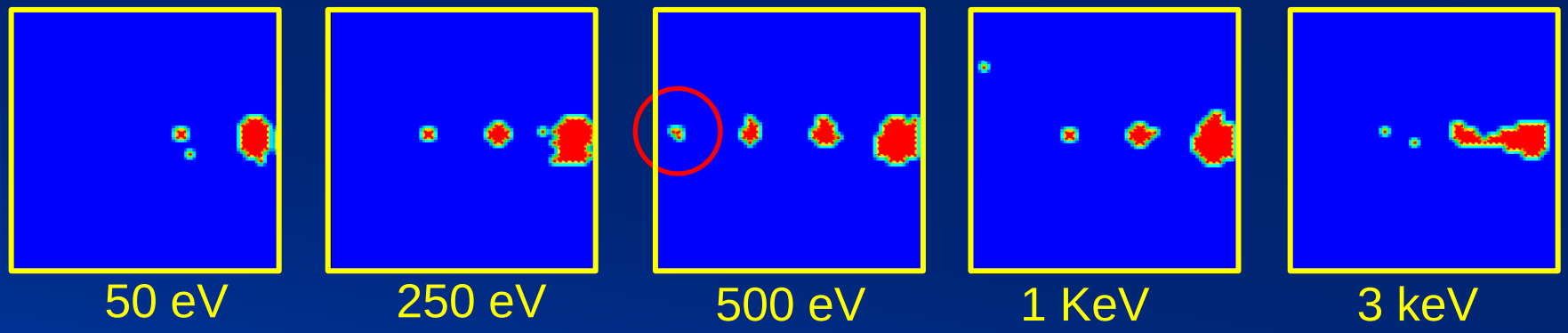
S. Iida et al. BACUS 2014

B_4C capped ML sample

Intrusion defect



Extrusion defect



Difference image

$$\text{Defect detection}: \frac{Defect\ signal\ intensity}{Back\ ground\ noise} = 10\ \sigma$$

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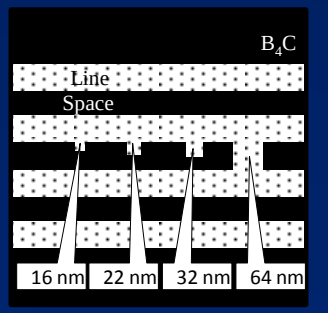
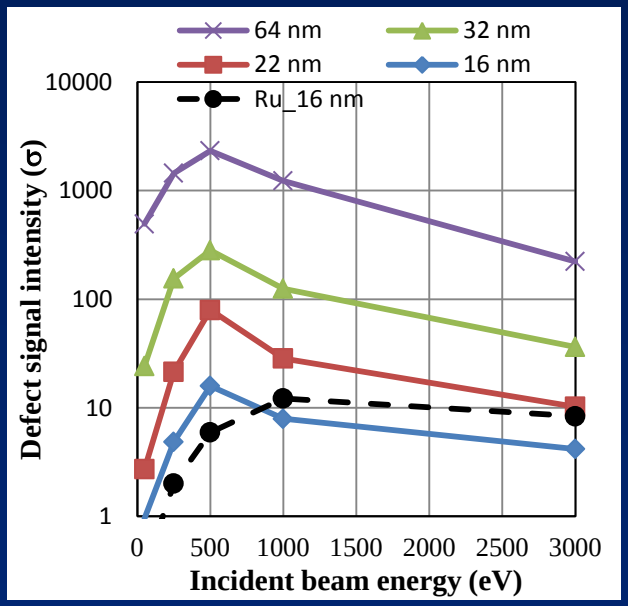
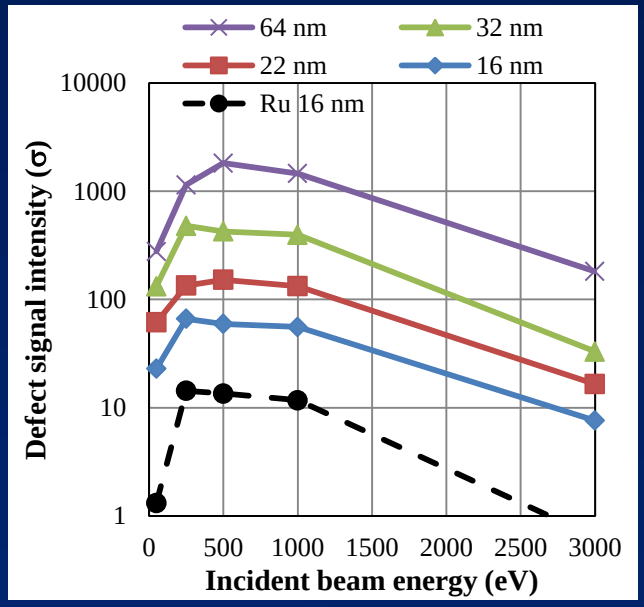
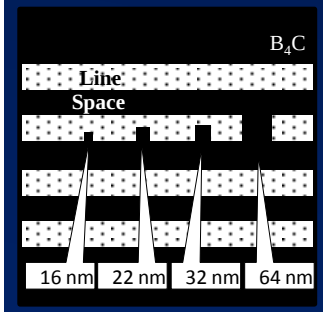
Defect signal intensity for B_4C sample



Extrusion

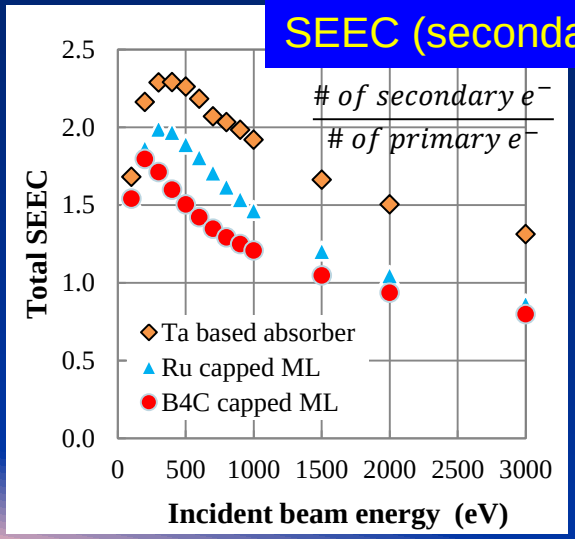


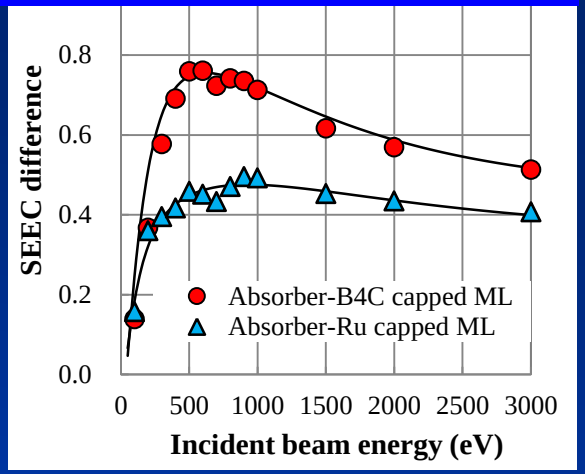


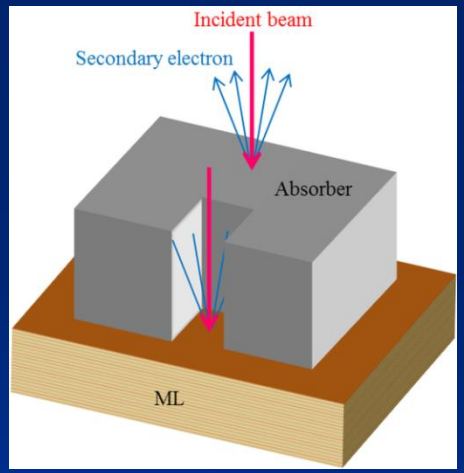


Intrusion

SEEC (secondary electron emission coefficient)







SEs from the ML are blocked by the side wall of the small defect

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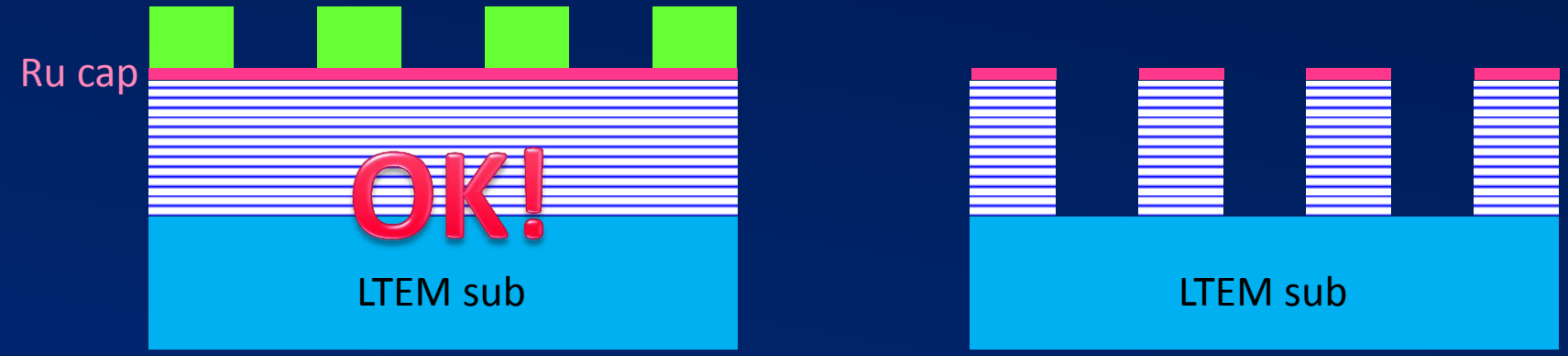
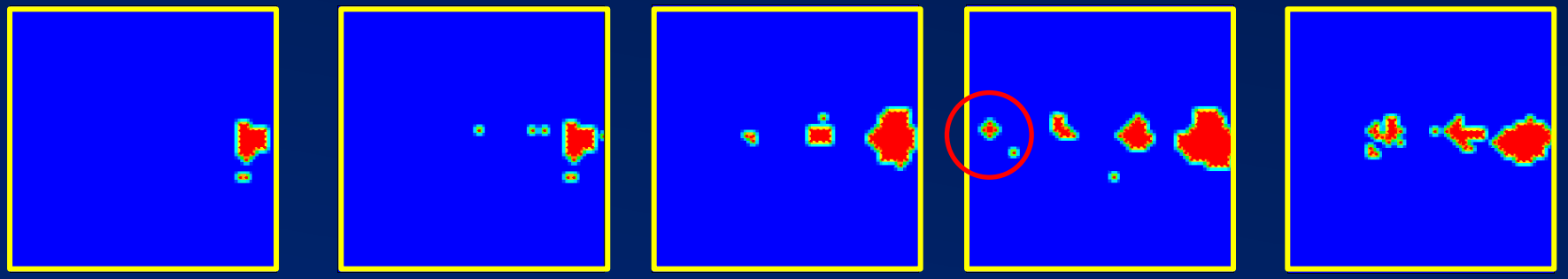
Proposed EUV mask structure



Inspection tools will be required to have high versatility.

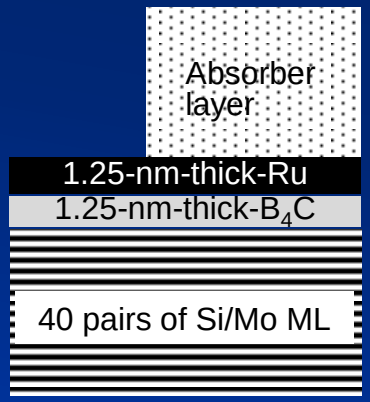
B_4C buffered
Ru capped ML

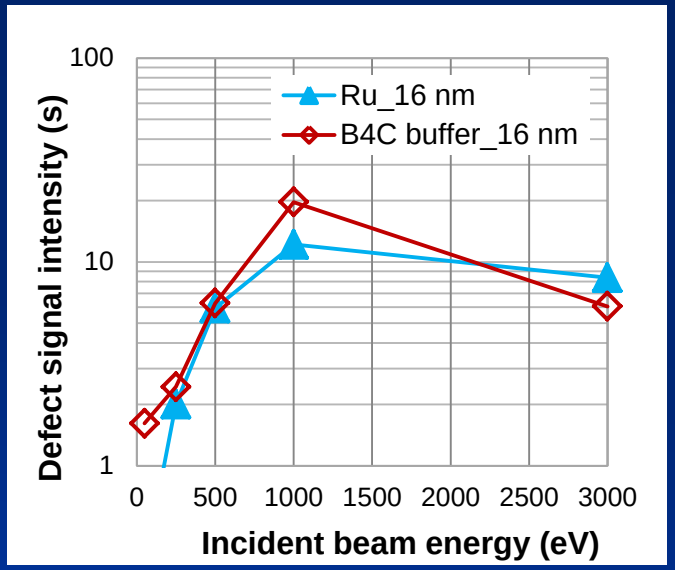
B_4C buffered Ru capped ML

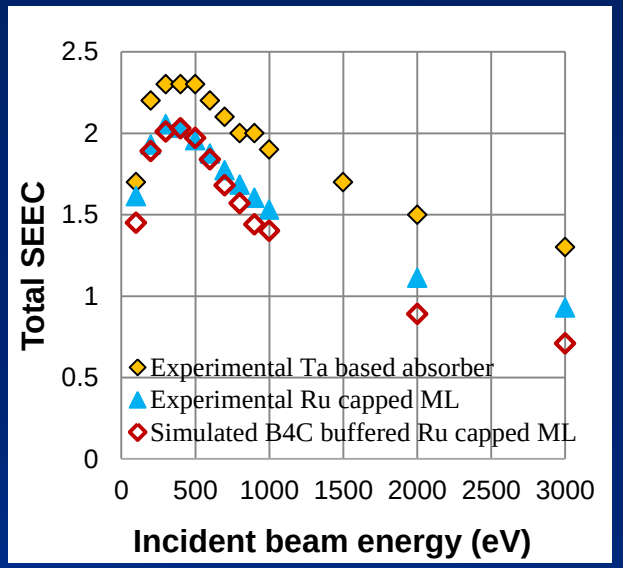


50 eV 250 eV 500 eV 1 KeV 3 keV

Difference image







SEECs of B_4C buffered Ru capped ML are lower than those of Ru due to thinner Ru and underlying low SEEC materials. As a result, the detectability increases.

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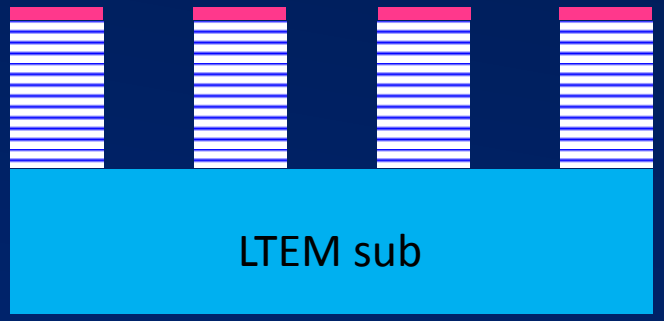
Proposed EUV mask structure

Ru cap

ML etched MASK



Inspection tools will be required to have high versatility.

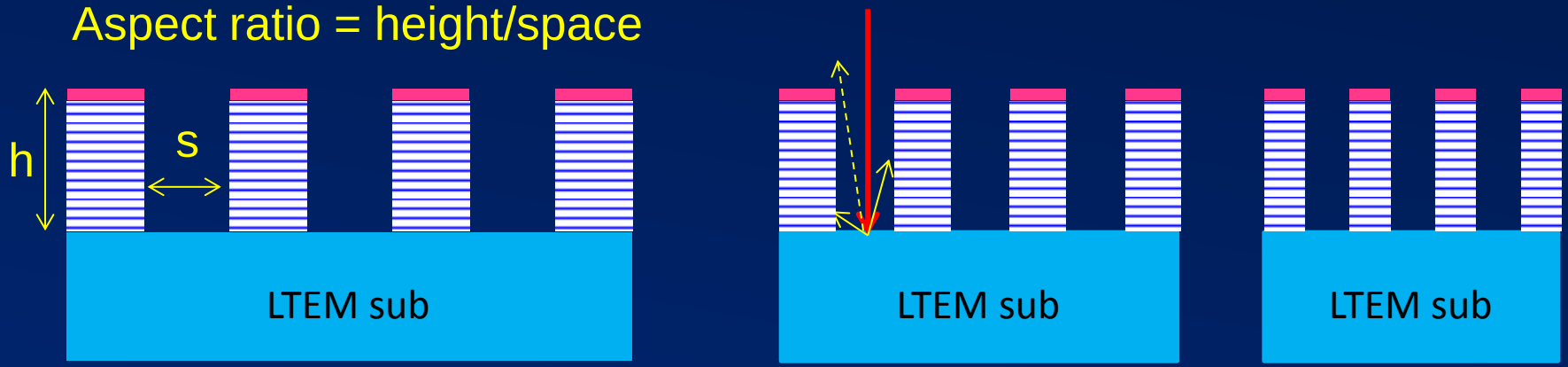
B_4C cap

Ru cap
B_4C buffer

B_4C buffered

Etched ML mask (for high NA)

Aspect ratio = height/space

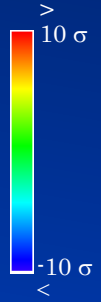


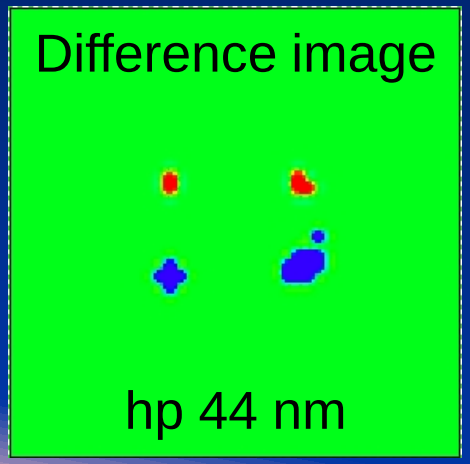
hp 44 nm
Aspect ratio = 6.4

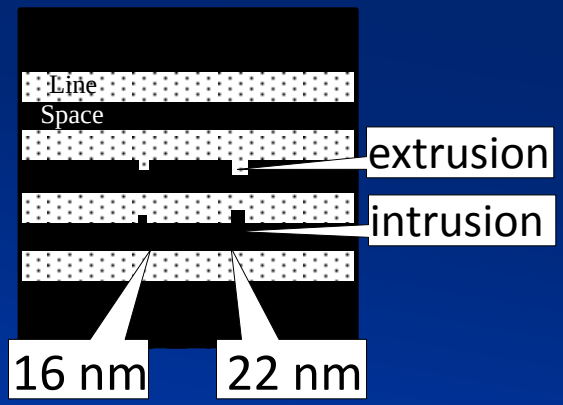
hp 40 nm
Aspect ratio = 7.0

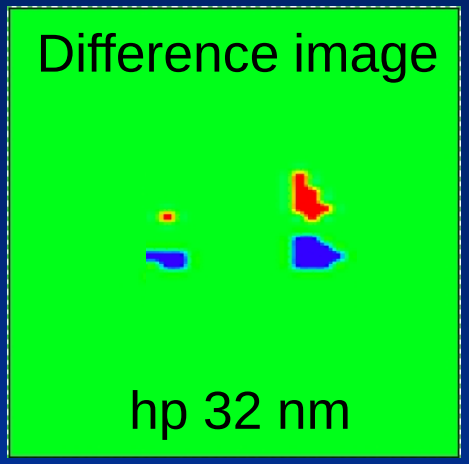
hp 32 nm
Aspect ratio = 8.8

High aspect ratio → advantage for high image contrast
(low signal intensity from the bottom of the space)









Proposed EUV mask structure

Ru cap

ML etched MASK

Simulation results show the high versatility of PEM!

B_4C cap

Ru cap
B_4C buffer

B_4C buffered

Summary and conclusions

- Impact of EUV mask structure on defect detectability of Patterned mask Inspection using PEM was investigated
- Simulation results were in good agreement with the tool performance in case of Ru capped ML mask
- 16 nm defect found to be detected more than 10 σ on EUV mask with Ru and B_4C capping layer, B_4C buffered Ru capping layer, and Etched ML Mask
- SEEC (secondary electron emission coefficient) was found to be strong tool to optimize the inspection condition.
- Simulation results show the high versatility of PEM

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Takashi Kamo, Kosuke Takai, Masato Naka Ryoji Yoshikawa, and Takashi Hirano of Toshiba

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Thank you for your attention

Paper list

Susumu Iida, Ryoichi Hirano, Tsuneo Terasawa, Tsuyoshi Amano, and Hidehiro Watanabe

Jpn. J Appl. Phys 53, 116602 (2014) “Analysis of image distortion on projection electron microscope image”

Ryoichi Hirano, Susumu Iida, Tsuyoshi Amano, Tsuneo Terasawa, Hidehiro Watanabe, Masahiro Hatakeyama, Takeshi Murakami and Kenji Terao,

J. Micro/Nanolith. MEMS MOEMS. 13 (1), 2014, 013009 “Patterned mask inspection technology with projection electron microscope technique on extreme ultraviolet masks”

Susumu Iida, Tsuyoshi Amano, Ryoichi Hirano, Tsuneo Terasawa, and Hidehiro Watanabe

J. Vac. Sci. Technol. B 31(6), Nov/Dec 2013, 06F601 ”Impact of electron scattering in extreme ultraviolet reflective multilayer on electron image”

Susumu Iida, Tsuyoshi Amano, Ryoichi Hirano, Tsuneo Terasawa, and Hidehiro Watanabe

J. Micro/Nanolith. MEMS MOEMS. 12 (2), 2013, 023013 “Extreme ultraviolet mask defect inspection with a half pitch 16-nm node using simulated projection electron microscope images”

Tsuyoshi Amano, Susumu Iida, Ryoichi Hirano, Tsuneo Terasawa, Hidehiro Watanabe, Kenjiro Yamasoe, Mitsunori Toyoda, Akifumi Tokimasa, Tetsuo Harada, Takeo Watanabe, and Hiroo Kinoshita

Appl. Phys. Express 6 (2013) 046501 “Observation of Residual-Type Thin Absorber Defect on Extreme Ultraviolet Lithography Mask Using an Extreme Ultraviolet Microscope”

Ryoichi Hirano, Hidehiro Watanabe, Susumu Iida, Tsuyoshi Amano, Tsuneo Terasawa, Masahiro Hatakeyama, Takeshi Murakami

J. Micro/Nanolith. MEMS MOEMS. 12 (2), 2013, 021003 “Development of extreme ultraviolet mask pattern inspection technology using projection electron beam optics”

Susumu Iida, Tsuyoshi Amano, Ryoichi Hirano, Tsuneo Terasawa, and Hidehiro Watanabe

J. Vac. Sci. Technol. B 30(6), Nov/Dec 2012, 06F503-1 “Identification of residual-type defect on extreme ultraviolet mask by projection electron microscope using Monte Carlo simulation”

Tsuyoshi Amano, Susumu Iida, Ryoichi Hirano, Tsuneo Terasawa, Hidehiro Watanabe, and Yuichi Inazuki

J. Vac. Sci. Technol. B 30(6), Nov/Dec 2012, 06F501-1 “Residual-type mask defect printability for extreme ultraviolet lithography”