2007 International EUVL Symposium

28-31 October 2007, Sapporo Convention Center, Sapporo, Japan

Evaluation of EUV Mask Repair Methods for Si-capping & Ru-capping Blanks

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Photomask Team

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everyone's invited™

Outline

- Introduction
- Experimental conditions
- Results
  - Mask repair results
  - Wafer printability
  - Actinic inspection
- Conclusions

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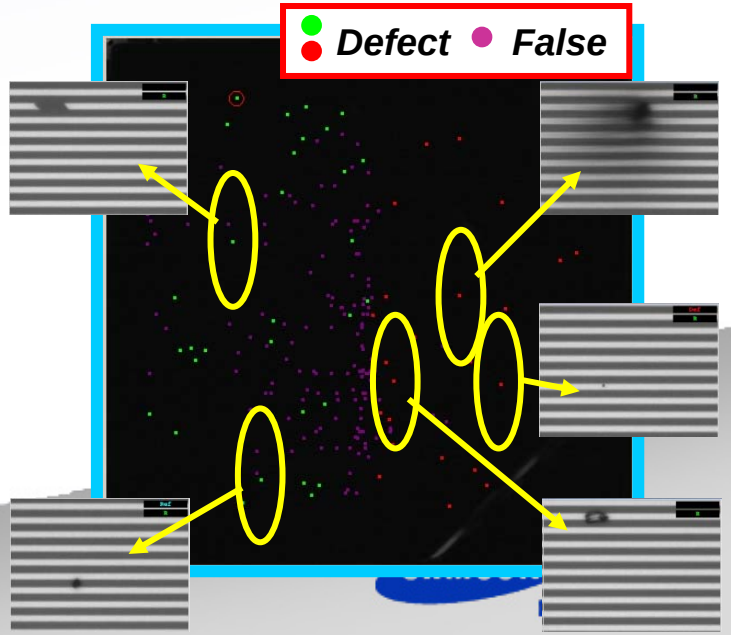
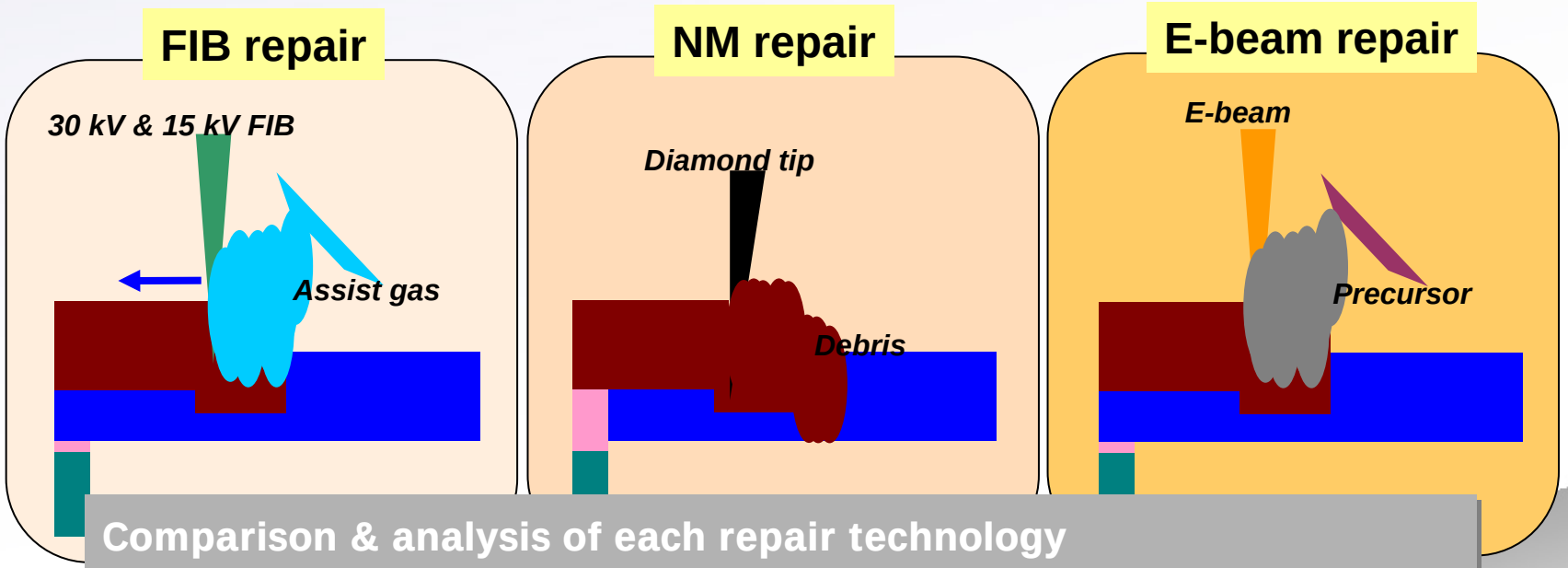
Introduction

- **Defect in EUV mask**
  - Blank defect : substrate defect, multi-layer defect(buried defect)
  - **Process defect(amplitude defect)**
    - **Possibility of defect generation in mask process**
- **Repair technology for EUV mask**
  - Major obstacles against High Volume Manufacture
    - **Accuracy**
    - **Multi-layer damage**
  - Adequacy for EUV mask repair
    - **How to evaluate…**
    - **MET & AIT @ LBNL**

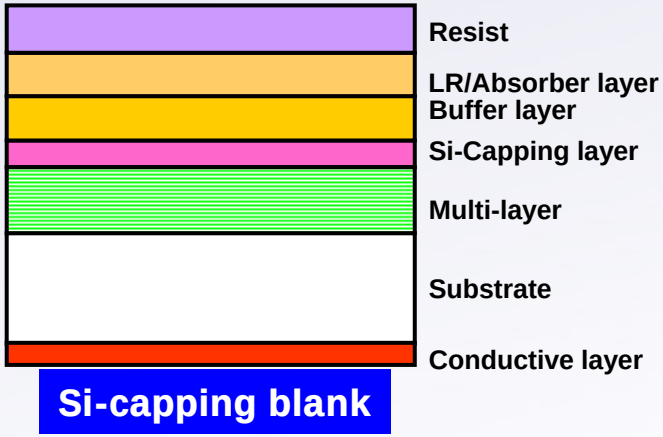


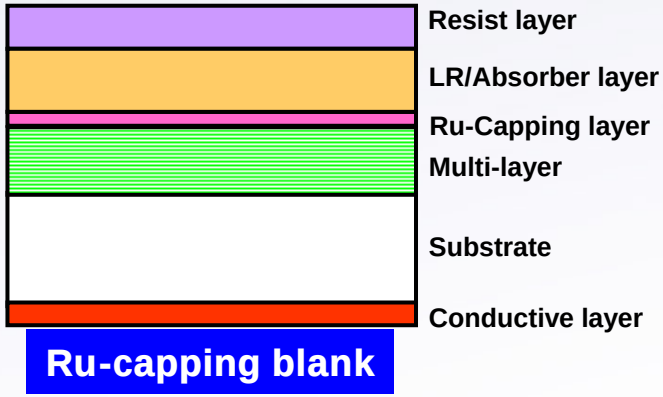
- **Available repair technologies for EUV mask**
  - FIB : Familiarity, ML damage caused by ion implantation in 30keV FIB
    - Capability of low accelerating voltage ➔ small ML damage, higher potential than 30keV
  - Nano-machining : Low substrate damage, surface roughness
    - Limitation of pattern geography, Throughput and tip life time
  - E-beam : High etching selectivity, low substrate damage by reaction between absorber layer and precursor



Comparison & analysis of each repair technology
➔ Selection of an optimal EUV repair technology or combination
Evaluation of their capability

- **Available EUV blank type**
  - Si-capping & Ru-capping blank





	w/ buffer layer (Si-capping)	w/o buffer layer (Ru-capping)
Structure	Buffer layer to protect capping & ML	Ru capping as buffer layer & capping layer
Advantage	▪ Relatively few blank defect ▪ Strong against ML damage	▪ Simple mask process ▪ Strong at capping surface contamination
Disadvantage	▪ Weak at capping surface contamination ▪ Hard to repair buffer defect	▪ Relatively many blank defect ▪ Vulnerable to ML damage in repair process ▪ Possible toxic Ru-oxide

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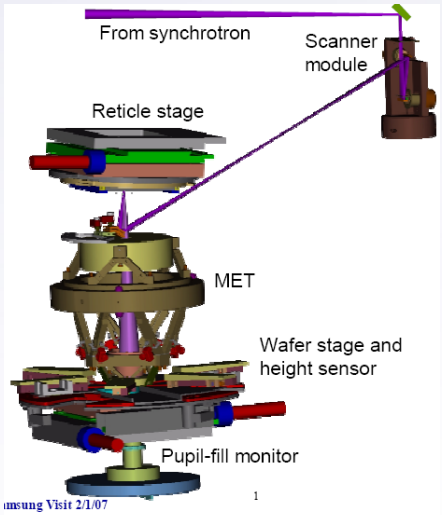
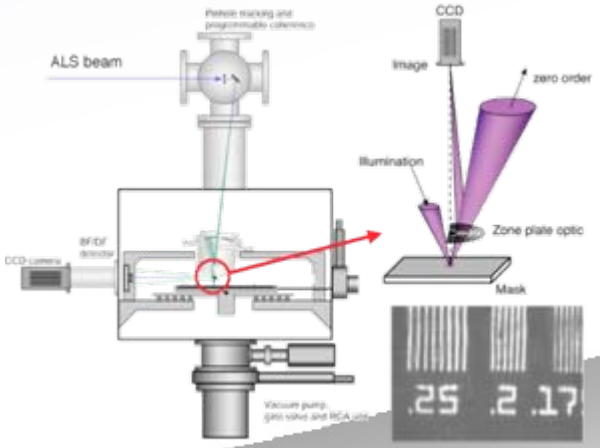
Experimental conditions

- **Blank mask**
  - Si-capping blank
  - Ru-capping blank
- **Mask repair tool**
  - 15keV-FIB
  - Nano-machining
  - E-beam
- **Micro Exposure Tool (MET)**
  - Exposure Conditions
    - Exposure tool : LBNL MET
    - NA 0.3, 5X,
    - Incident angle : 3.6˚
    - Annular, sigma 0.30/0.55
- **Actinic Inspection Tool (AIT)**
  - Imaging mode
    - Resolution
      ~100 nm, Mask
      ~25 nm, 4× Wafer equivalent
    - Magnification : 700x
    - *NA* = 0.0625 (0.25 NA, 4x stepper)



Naulleau (LBNL), et al., *SPIE 2005*



Goldberg (LBNL), et al., *JVST B 2006*

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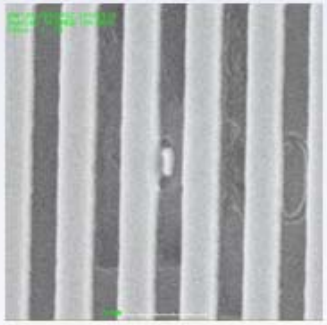
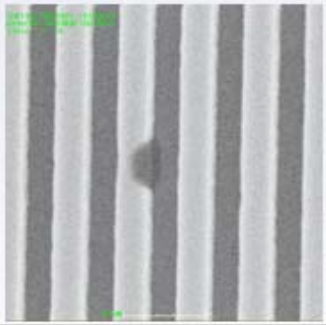
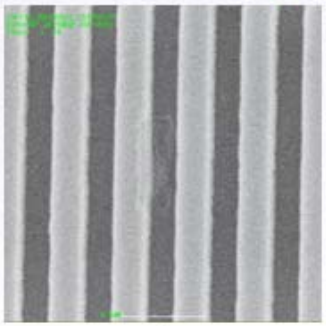
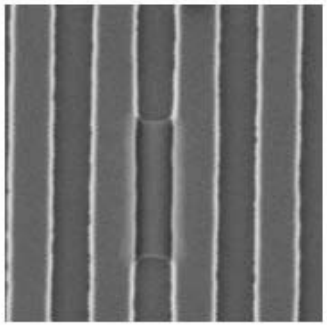
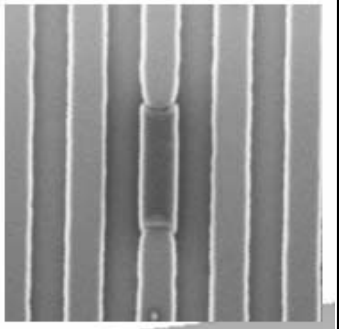
Repair result on sample mask

	Etch	Depo.	
15keV-FIB			▪Etch : Small substrate damage comparing to 30keV ▪Depo. : Small substrate damage comparing to etch
Nano-machining			▪Morphology on surface ▪Over-offset → capping layer damage
E-beam			▪Etch : Minimum substrate damage ▪Undercut at Boundary between defect and pattern ▪Depo. : Minimum substrate damage ▪Roughness around joint aera

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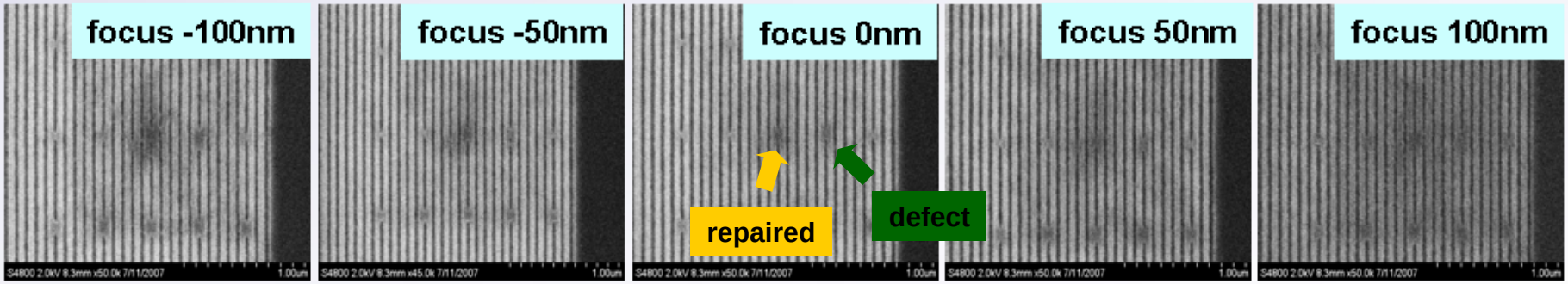
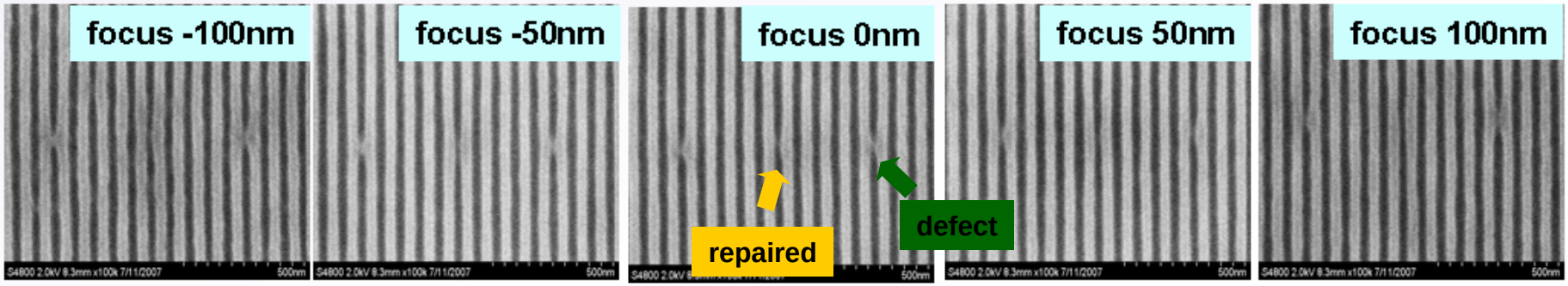
Through focus behavior of 15keV-FIB etch repair

Ru capping 40nm



Si capping 40nm



40nm Ru-capping : Local reflectivity drop by ion-implantation
➔ Serious edge roughness and bridge
40nm Si-capping : No scan damage, but accuracy problem
➔ Small reflectance change was observed in repaired area through little mask surface damage.

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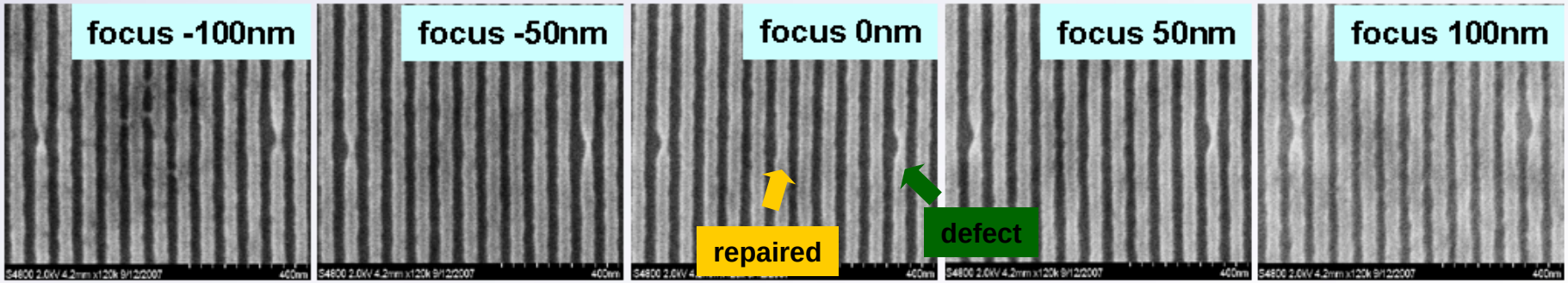
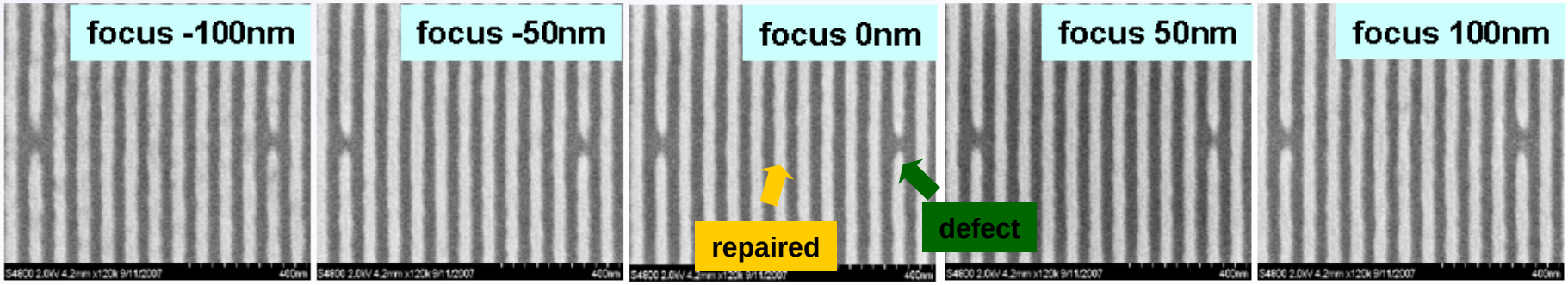
Through focus behavior of 15keV-FIB depo. repair

Ru capping 40nm



Si capping 40nm



40nm Ru-capping : Local reflectivity drop by ion-implantation
➔ Serious edge roughness and bridge
40nm Si-capping : No scan damage
➔ Small reflectance change was observed.

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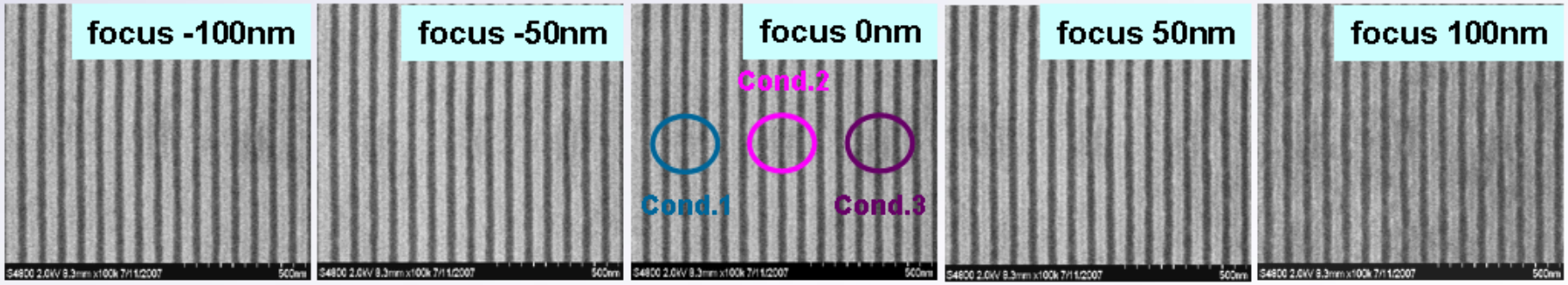
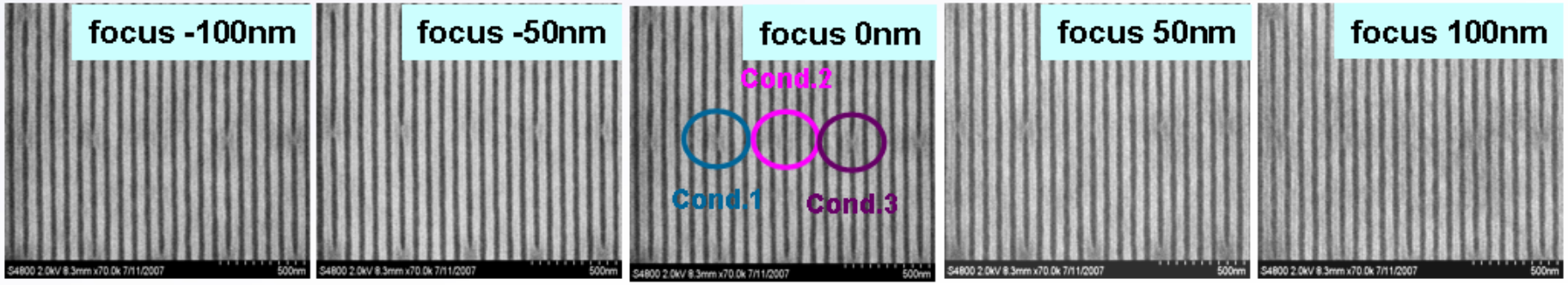
Through focus behavior of nano-machining repair

Ru capping 40nm



Si capping 40nm



3 repair conditions are implemented on a field

Ru-capping : No scan damage

➔Better repairability than FIB

➔1st condition is the best among them

Si-capping : No scan damage

➔Better repairability than FIB

➔2nd condition is the best among them

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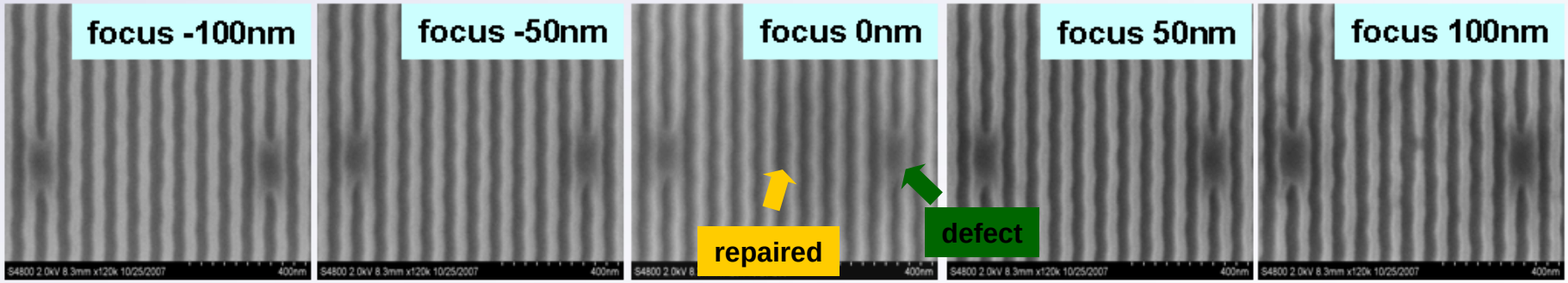
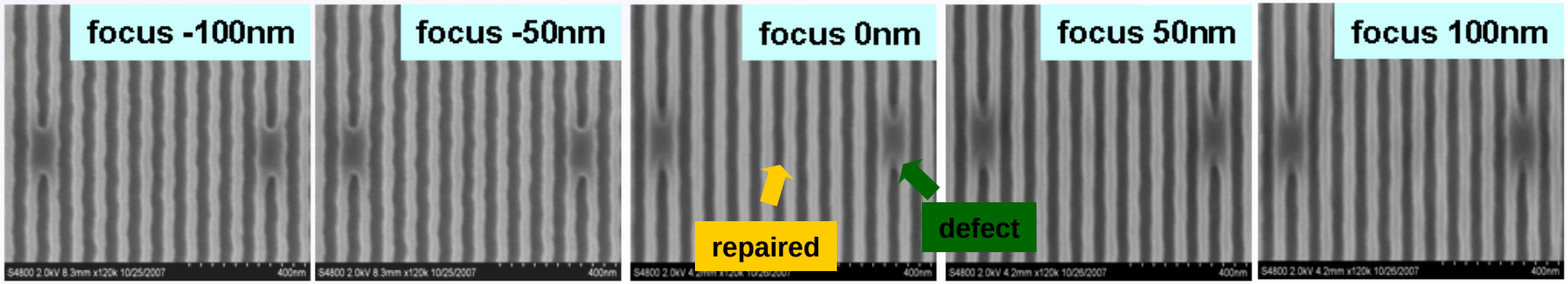
Through focus behavior of e-beam etch repair

Ru capping 40nm



Si capping 40nm



Big bridge repair for its capability
Repaired with the best condition from some pre-tests
40nm Ru-capping : No scan damage
40nm Si-capping : No scan damage
The best repair quality

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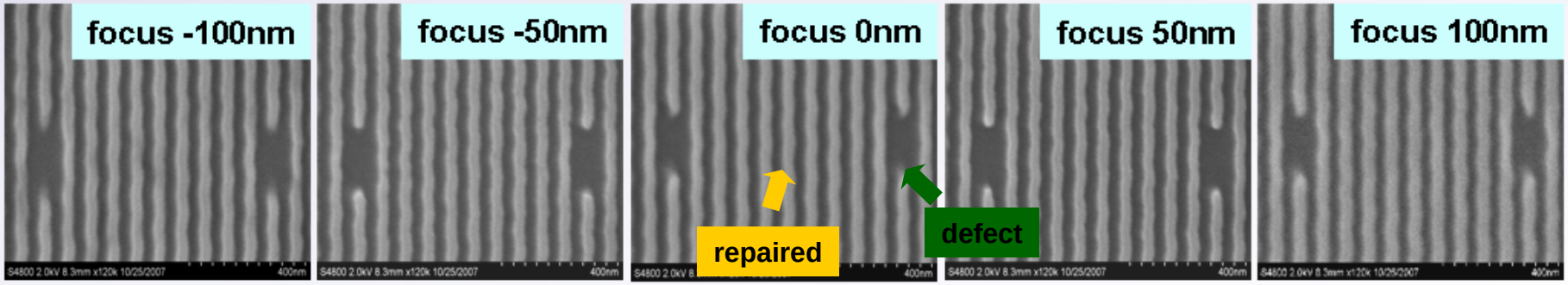
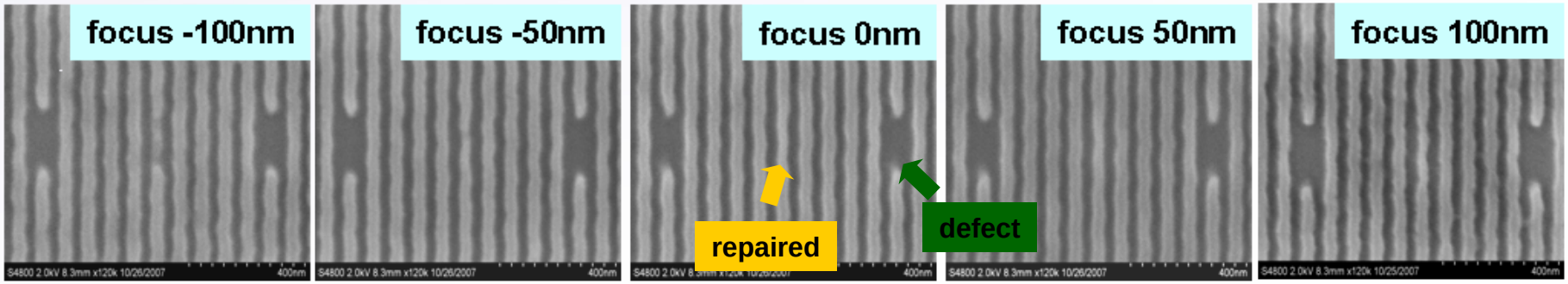
Through focus behavior of e-beam depo. repair

Ru capping 40nm



Si capping 40nm



Repaired with the best condition from some pre-tests
40nm Ru-capping : No scan damage, The best repair quality
40nm Si-capping : No scan damage, but repaired pattern thinning by buffer etch process
➔ CD change was observed in repaired area through buffer etch damaging bolster material.

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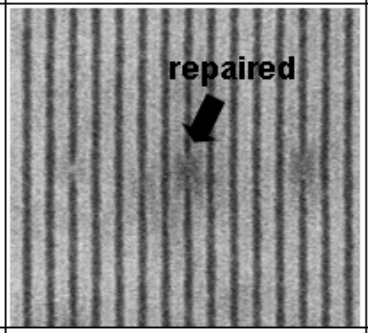
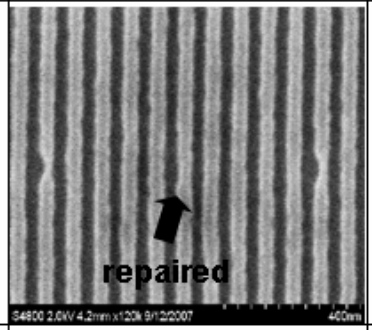
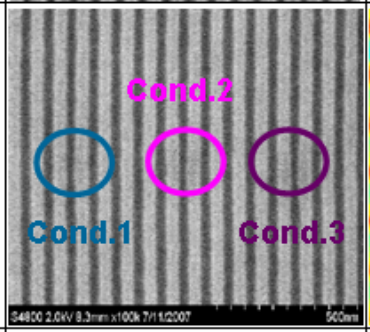
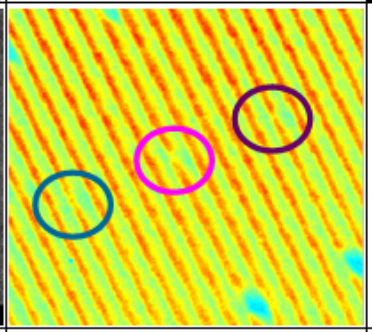
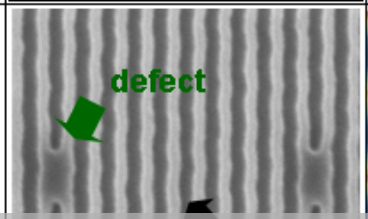
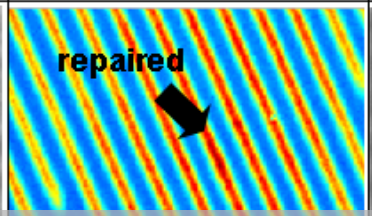
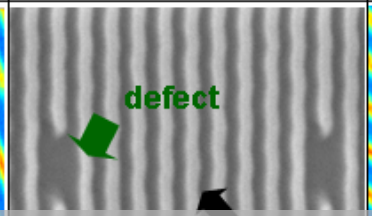
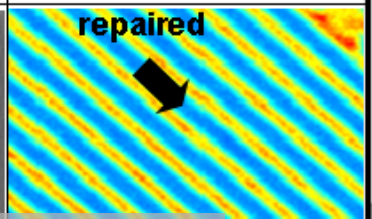
Comparing MET to AIT results of Ru-capping repair

	Etch repair		Depo repair	
	MET	AIT	MET	AIT
15keV FIB		N/A		N/A
Nano-machining			N/A	N/A
E-beam				

15keV FIB : Local reflectivity drop by ion-implantation
➔ Serious edge roughness and CD change
Nano-machining : No scan damage
E-beam : Best repair accuracy & No scan damage
AIT results are well matched with MET result.

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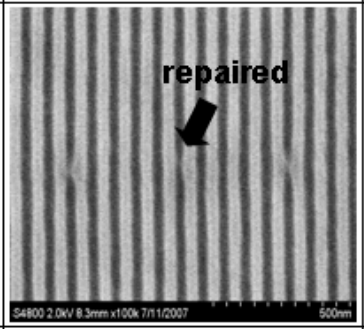
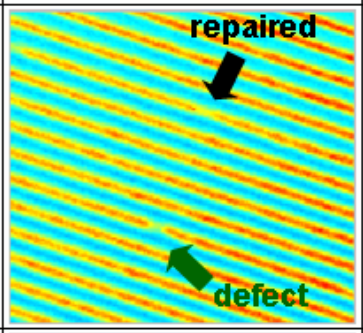
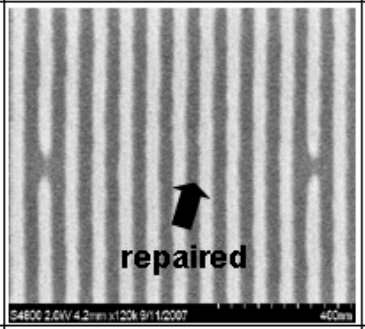
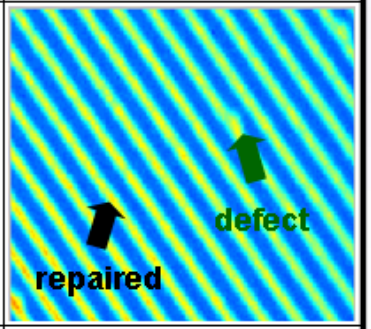
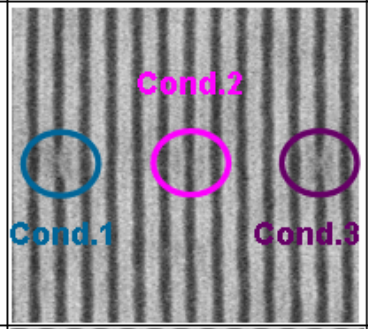
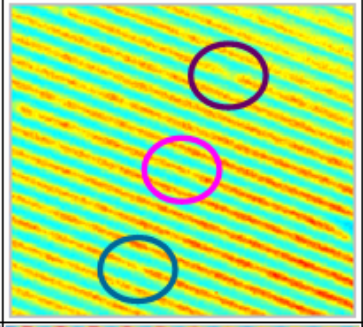
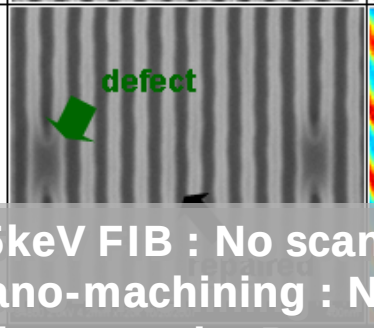
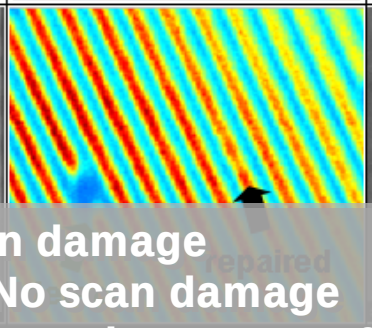
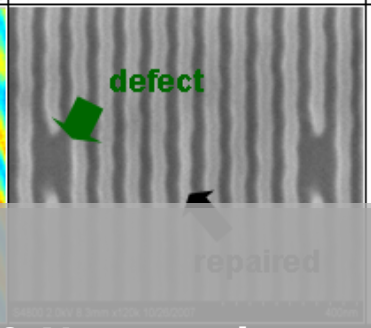
Comparing MET to AIT results of Si-capping repair

	Etch repair		Depo repair	
	MET	AIT	MET	AIT
15keV FIB				
Nano-machining			N/A	N/A
E-beam				N/A

15keV FIB : No scan damage
Nano-machining : No scan damage
E-beam etch : Best repair accuracy & No scan damage
E-beam depo. : Repaired pattern damaged by buffer etch
AIT results are well matched with MET result.

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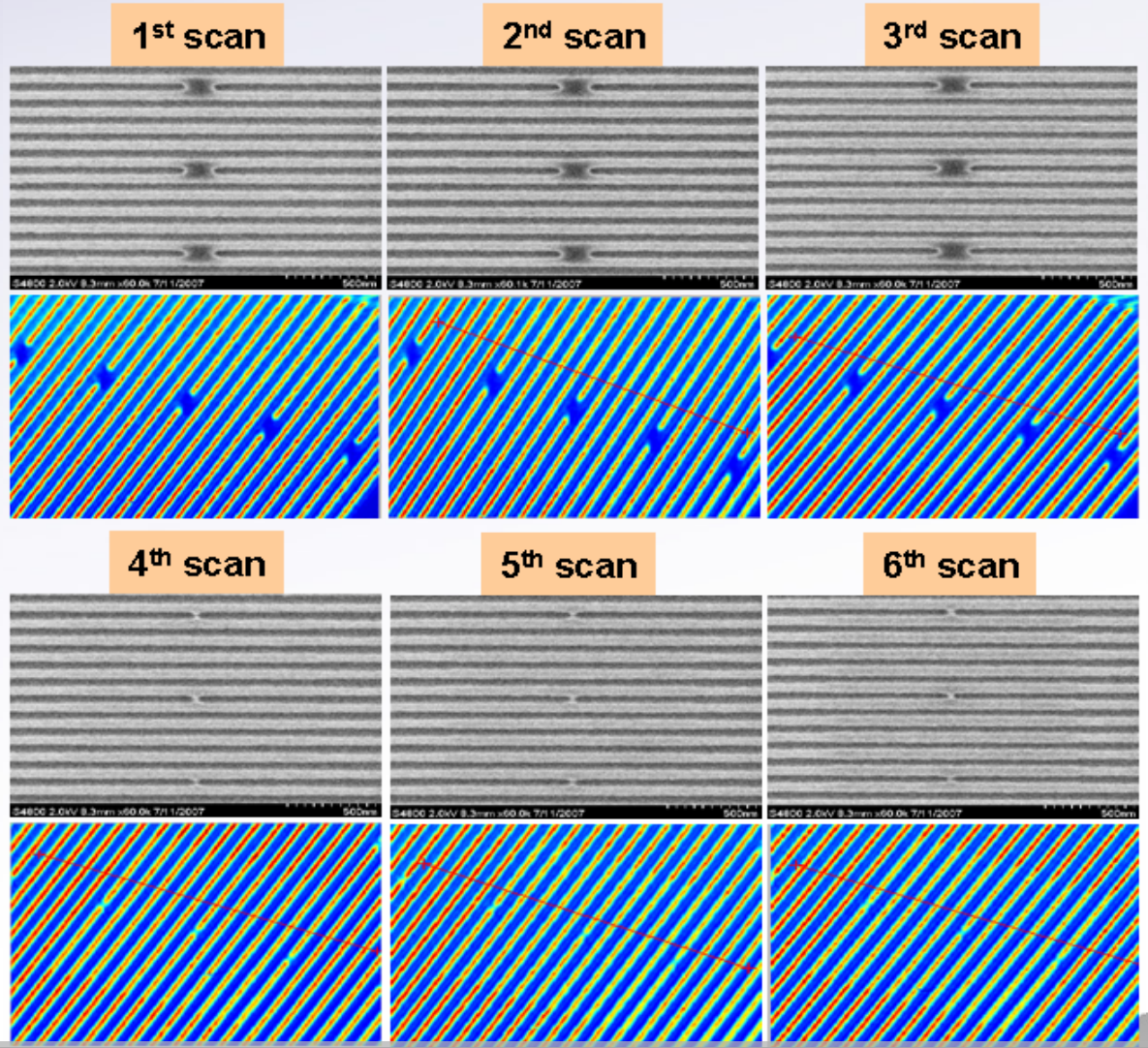
Scan damage from FIB on Ru-capping mask



Ru-capping : Local reflectivity drop by ion-implantation

➔ As the time increased, severe reflectivity change was observed in scan area through multi layer damage.

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Conclusion

- Need to find the best solution for EUV mask repair
  - ➔ Evaluation of FIB, nano-machining, e-beam repair technology

	Si-capping mask	Ru-capping mask
15keV FIB	No scan damage to 40 & 60nm node Accuracy issue for sub-30nm	Scan damage in 40 & 60nm node No capability
Nano-machining	No multi layer damage	No multi layer damage
	Need more accuracy for sub-30nm Need productivity analysis Throughput & Tip life time	
E-beam	Scan damage free & best repair	Scan damage free & best repair
	Undercut (mask) ➔ Need more precise recipe Need productivity analysis Throughput	

- AIT results are totally matched with METs.
  - ➔ Aerial image analysis more effective for repair evaluation
    - wafer pattern depends on resist property.

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- Three technologies (E-beam, nano-machining, low accelerating voltage FIB) have enough potential for EUV mask repair.
- With the issue of ML damage & accuracy, 15keV-FIB technology could not support Ru-capping mask.
- Even though E-beam & nano-machining repair technologies are the strongest candidates, needs more improvement in tool & recipe for sub-30nm EUV mask repair.

➔ E-beam repair : recipe preventing undercut phenomenon

➔ nano-machining repair : accuracy covering sub-30nm repair

Good Normal Bad

	Resolution	Edge placement	Multi layer damage	Removal selectivity	Geographical dependency	Throughput	Familiarity
15keV FIB	Normal	Normal	Bad	Normal	Good	Normal	Good
Nanomachining	Normal	Good	Good	Normal	Bad	Bad	Good
E beam	Good	Good	Good	Good	Good	Normal	Normal

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Acknowledgement

- Thanks to Kenneth A. Goldberg for AIT support at Lawrence Livermore National Laboratory.
- Thanks to Patrick Naulleau, Paul Denham, Brian Hoef, and Gideon Jones for MET support at Lawrence Livermore National Laboratory.
- Thanks to Hoon Kim & Dong-Wan Kim, Samsung Electronics.

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