Advanced Mask Inspection and Metrology

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Outline

- Introduction
- Requirements of photomask for resolution enhancement
- Defect inspection for photomask
- Metrology for Photomask
- Activity of Inspection for NGL mask
- Summary

- **Introduction**
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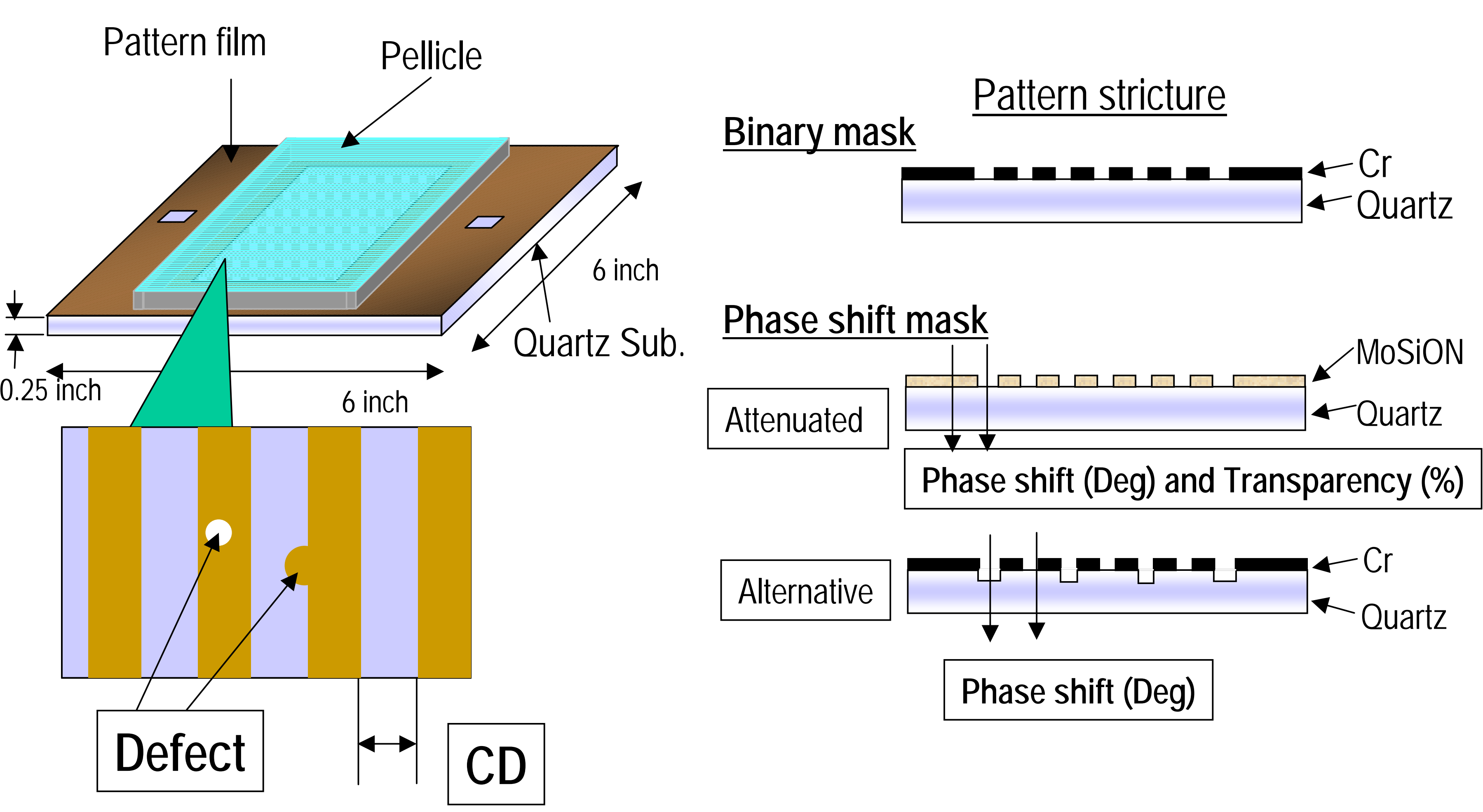
Wavelength Gap

Inspection wavelength 1
Inspection wavelength 2
555nm
488nm
364nm
257nm
266nm
198nm
g-line
i-line
KrF
ArF
F2
Lithography wavelength
Minimum feature size
Wavelength (nm)
1000
500
400
300
200
100
50
1980
1990
2000
2010
Year

Quality specifications Items of photomask



Roadmap for Photo Mask Technology

ITRS - 2002 Update *Optical Mask Requirements*	*2001* *130nm*	*2003* *100nm*	*2004* *90nm*	*2006* *70nm*	*2007* *65nm*
Lithography technology	Optical	Optical	Optical	Optical	Optical
Magnification	4	4	4	4	4
Mask minimum image size(nm)	360	260	212	160	140
Mask OPC feature size(nm) Opaque	180	130	106	80	70
Image placement(nm,multi-point)	27	21	19	15	14
CD uniformity(nm,3sigma)					
Isolated line(MPU gates) Bin.	7.4	5.1	4.2	3.4	2.5
Dense lines(DRAM half pitch)	10.4	8.0	7.2	5.6	4.2
Contact/vias	8.0	6.1	5.3	4.3	3.2
Linearity(nm)	19.8	15.2	13.7	10.6	9.9
CD mean to target(nm)	10.4	8.0	7.2	5.6	5.2
Defect size(nm)	**104**	**80**	**72**	**56**	**52**
Data volume(GB)	64	144	216	486	729
Mask design grid(nm)	8	4	4	4	4
Att.PSM trans. Mean dev. (+/-% target)	5	5	5	4	4
Att.PSM trans. Uniformity (+/-% target)	4	4	4	4	4
Att.PSM phase Mean dev. (+/-deg.)	4	3	3	3	3
ALT. PSM phase Mean dev. (+/-deg.)	2	2	2	1	1
ALT.PSM phase Uniformity (+/-deg.)	2	2	2	1	1

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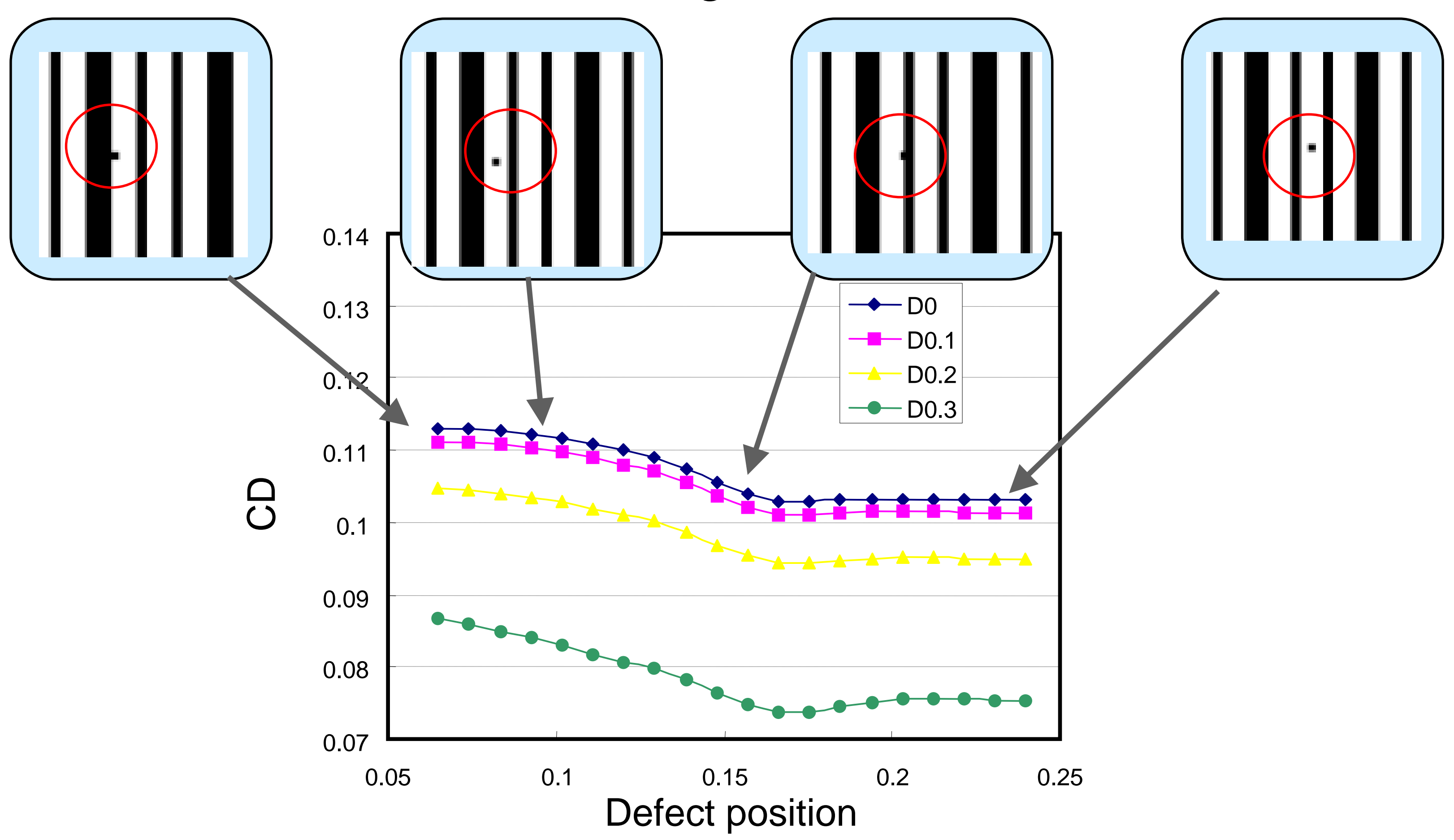
Defect Printability as Defect Positions



- Defects in assist bar area shows low printability

Effect of Contact Hole Size & Serif Variations

OPC

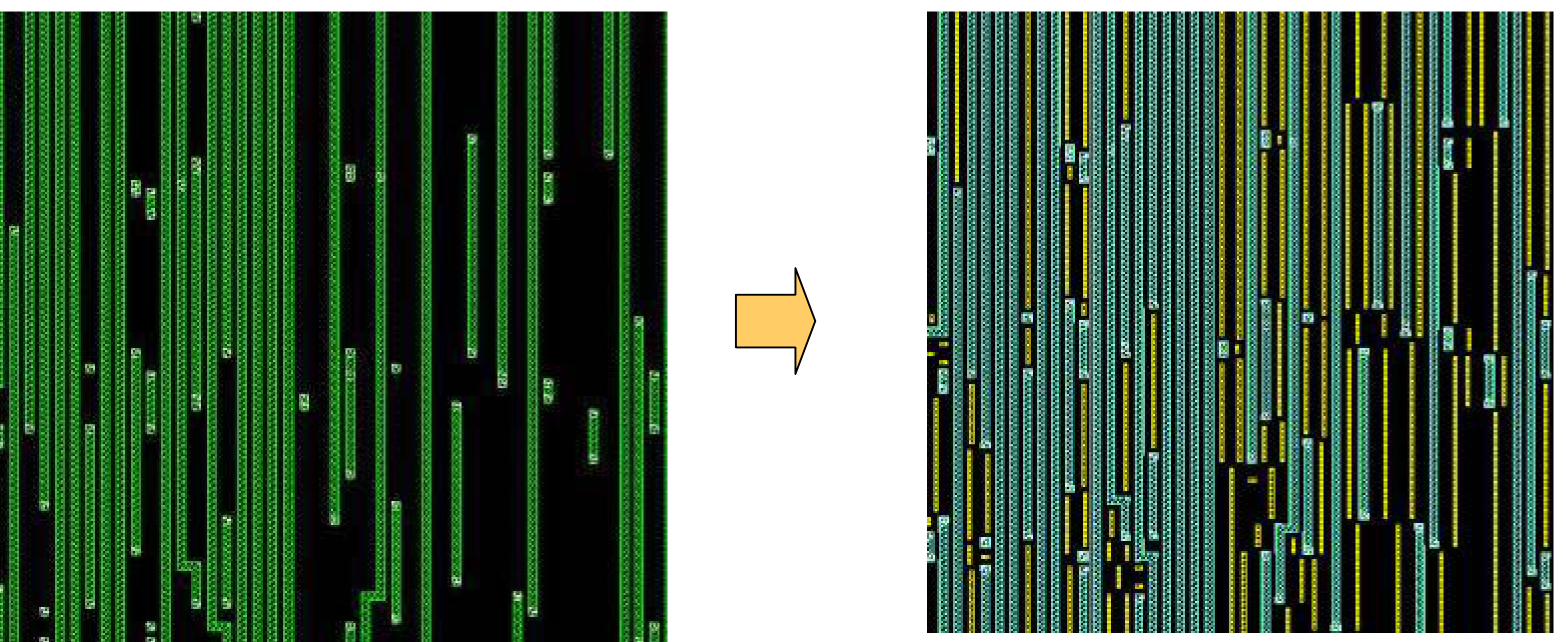
No OPC

OPC helps defect printability

Serif defect itself is not so important

Increase of Aggressiveness in OPC Technology

- Rule Based → Model Based → Rule + Model Based
- Aggressive OPC is inevitable option in low k1 lithography



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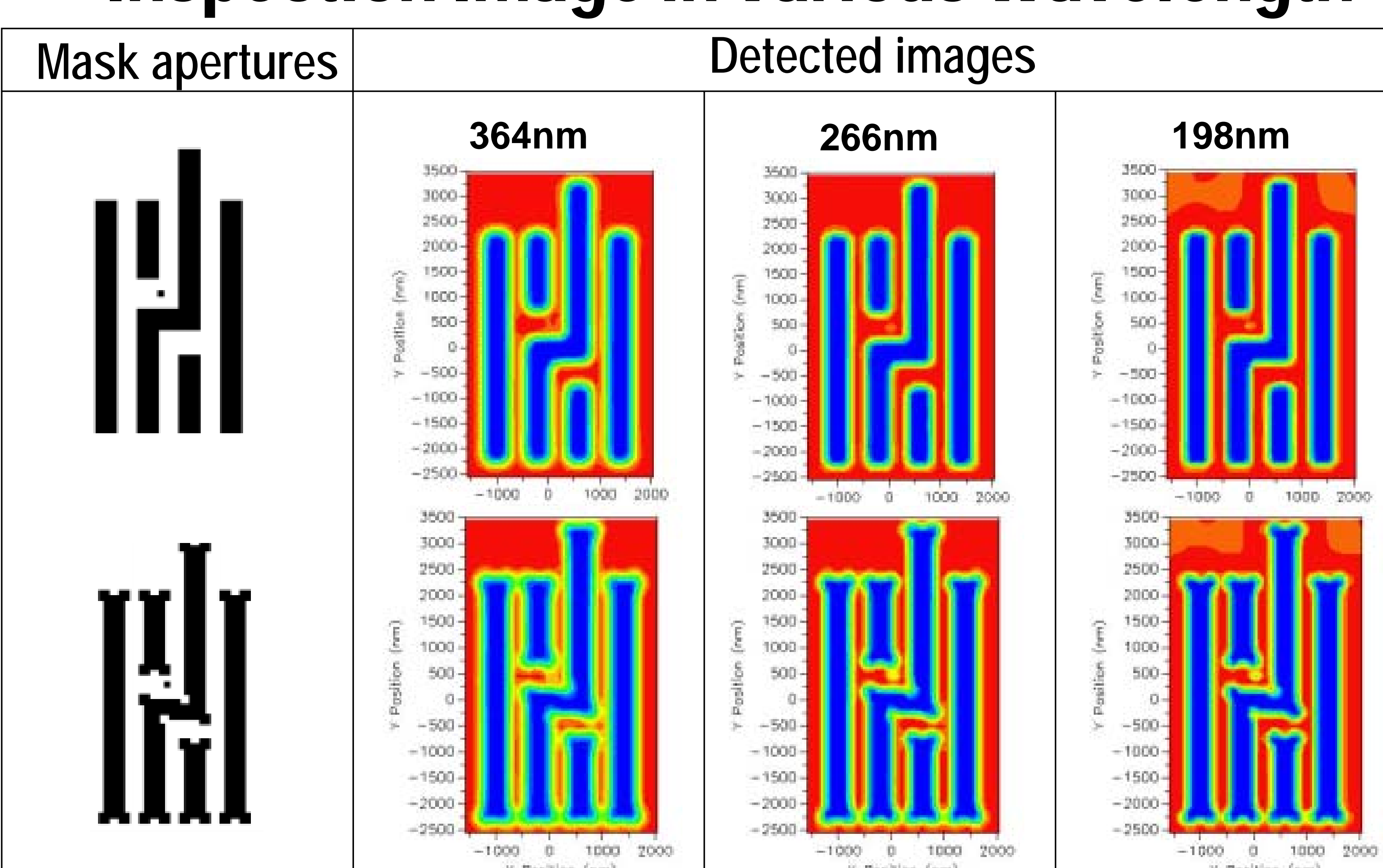
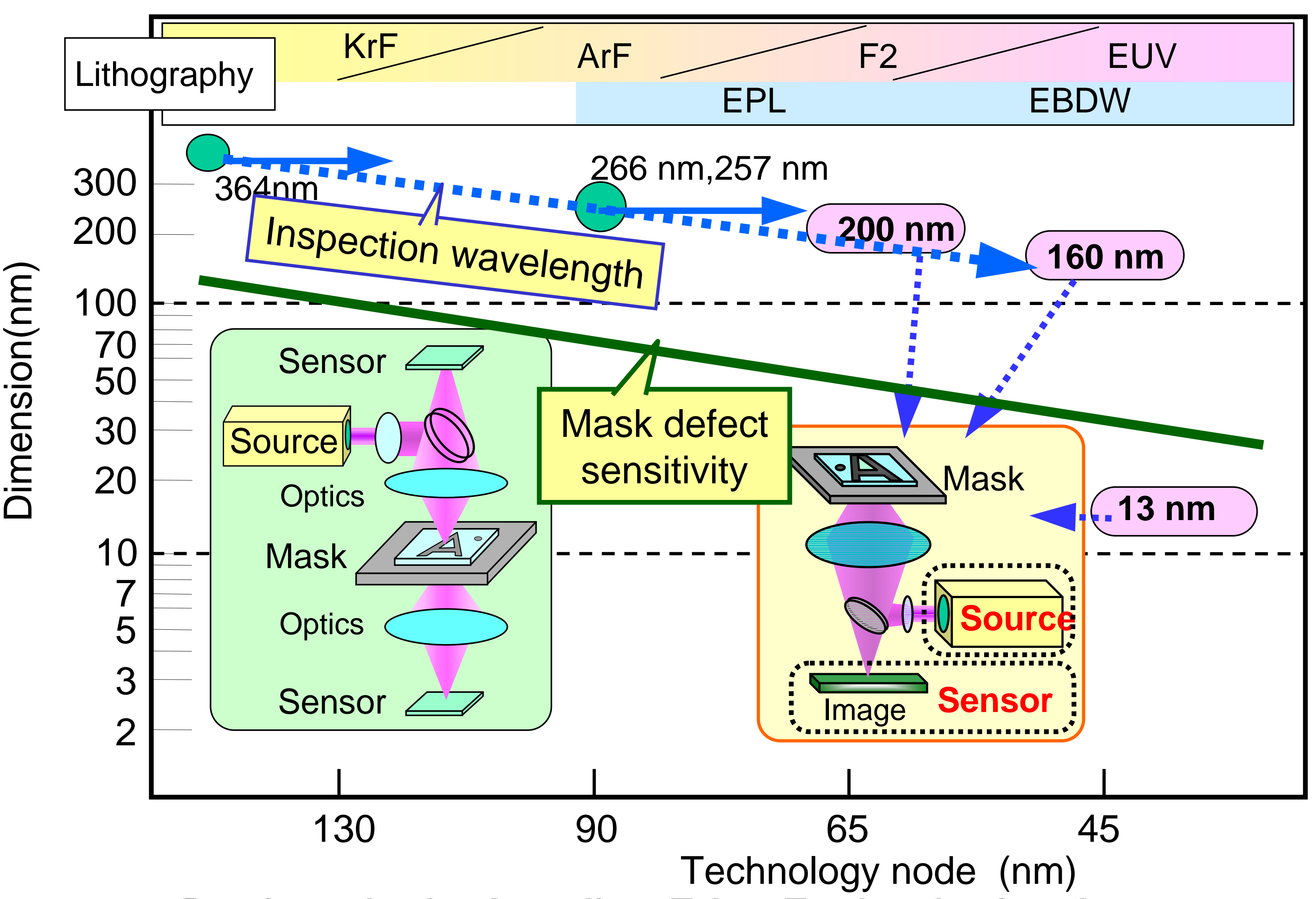
Revised Reticle Defect Size in ArF Lithography

Year of Production		2003 100nm	2004 90nm	2005 80nm	2006 70nm
Wafer minimum half pitch (nm)		100	90	80	70
Mask minimum image size (nm)		260	212	180	160
Mask OPC feature size (nm) Opaque		130	106	90	80
CD uniformity: Isolated lines (MPU gates) Binary		5.1	4.2	3.7	3.4
CD uniformity: Dense lines DRAM half pitch)		8.0	7.2	6.4	5.6
Defect size of ITRS (nm)		**80**	**72**	**64**	**56**
Cr dot (nm)	**1:1 pitch**	**103**	**96**	**91**	**58**
	1:2 pitch	**109**	**100**	**93**	**90**
Cr extension (nm)	**1:1 pitch**	**80**	**76**	**65**	**35**
	1:2 pitch	**85**	**89**	**91**	**93**
Oversize defect (nm)	**1:1 pitch**	**35**	**29**	**19**	**10**
	1:2 pitch	**40**	**36**	**30**	**22**
Undersize defect (nm)	**1:1 pitch**	**25**	**21**	**14**	**7**
	1:2 pitch	**30**	**27**	**23**	**16**

Inspection Image in Various Wavelength



Requirement of mask defect inspection



Requirements and Issues for Photomask Inspection

Technology node	130 nm		90 nm	65 nm	45 nm
Detection sensitivity (D) *	104 nm		72 nm	52 nm	35 nm
Inspection wavelength (l)	257 nm	365 nm	257 nm	200 nm	160 nm
Numerical Aperture	0.75	0.75	0.75	0.75	0.75
Nominal resolution (R) **	209 nm	296 nm	209 nm	163 nm	130 nm
Ratio of sensitivity and resolution (D/R)	0.5	0.35	0.34	0.32	0.27

*Minimum defect size which can be detected

**Rayleigh Limit : 0.61 l /NA

266nm wavelength Defect Inspection Tool

Main body

Image processing unit

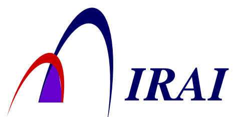
✓Development by joint with Selete and NEC

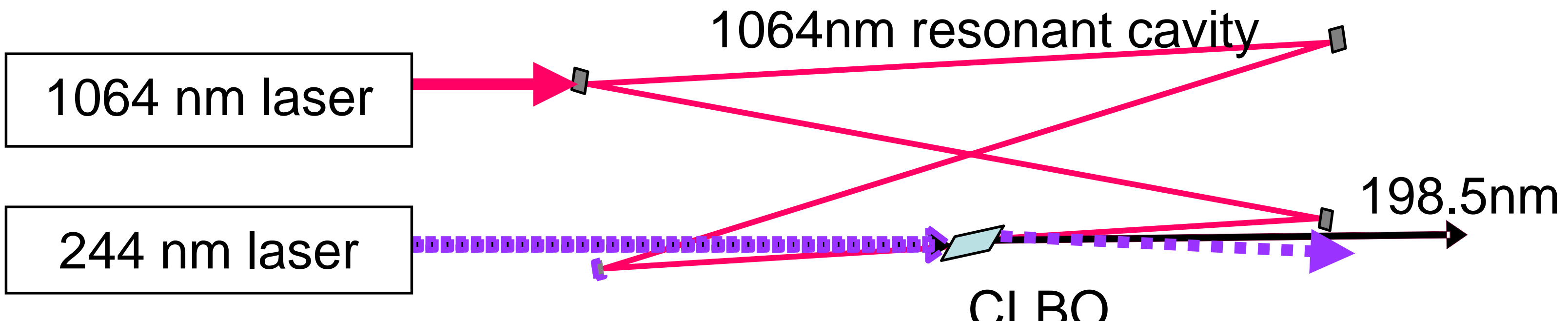
Target Spec.	
Defect Sensitivity :	80nm
Inspection mode:	Die-Die,Die-Data
Inspection Optical:	2 Beams Scan
Inspection Wavelength:	266nm

Present Progress Data

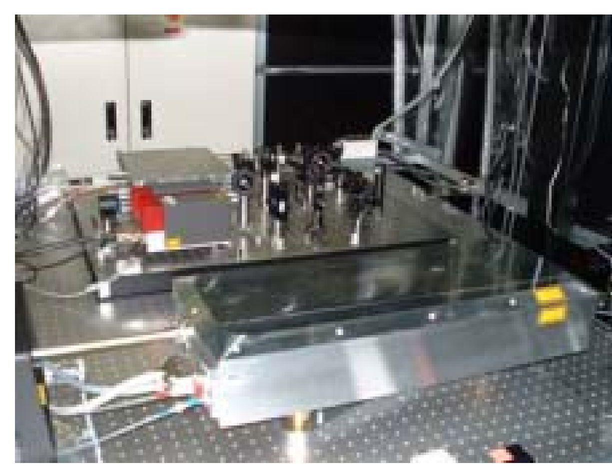
Defect type				
Sensitivity	75nm	70nm	70nm	60nm

Development of 198.5nm laser for mask inspection tool





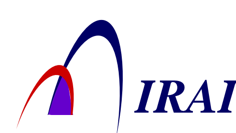
(a) Optical schematic of sum-frequency generation cavity



(b) Experimental Set up

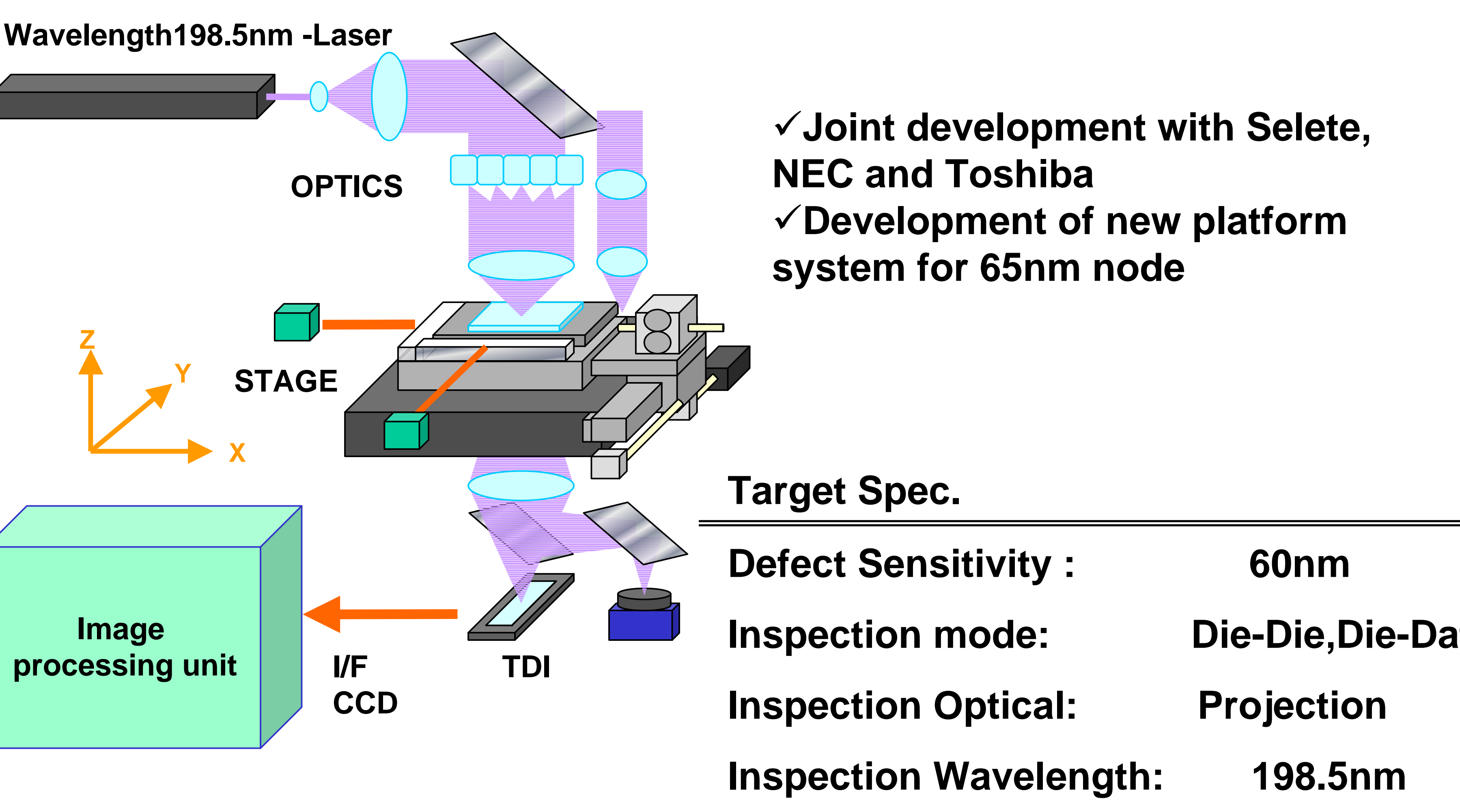
(c) 50 mW power

Deep UV sensitive CCD Architecture



Phosphor Coating	Virtual Phase	Poly Hole Gate	Backside Illumination
UV light Phosphor Visible light Poly gate Potential	UV light Poly gate Virtual gate	UV light Hole Poly gate	Poly gate 10μm UV light
Down convert UV light to Visible light by phosphor	Substitute poly gate with virtual gate	Make hole in poly gate which absorbs UV light	Illuminate from the backside of CCD thinned to about 10μm

Development of 198.5nm wavelength mask inspection tool



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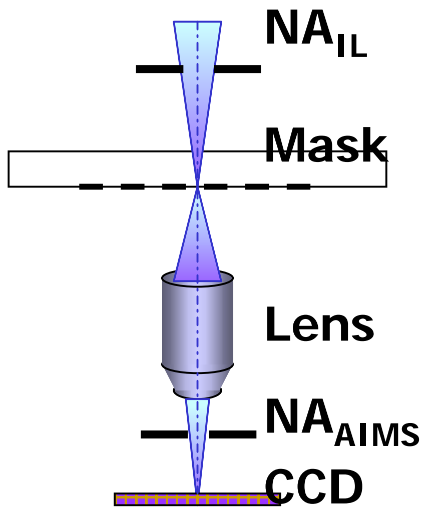
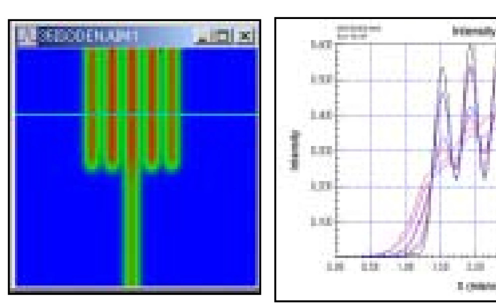
Requirements and Issues for Photomask Metrology

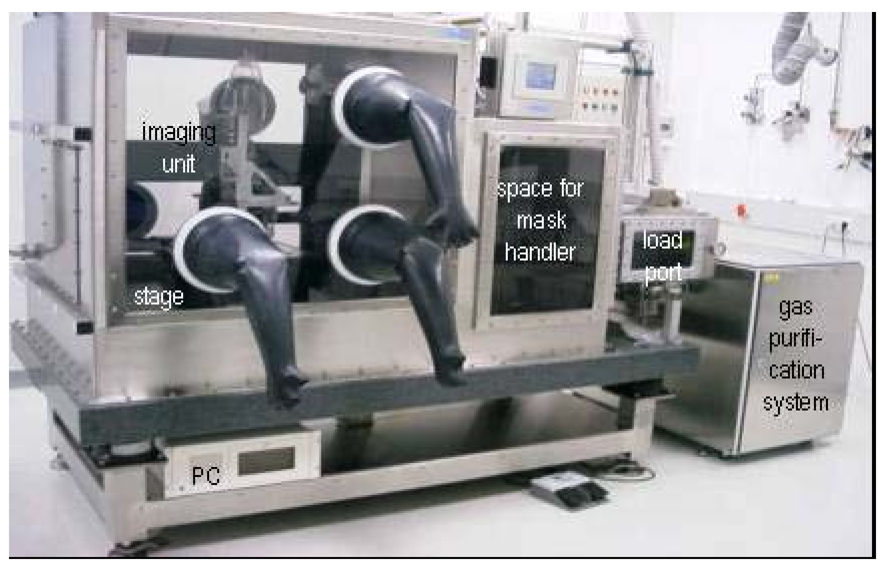
Year of production	2003 100 nm	2004 90 nm	2007 65 nm
Mask minimum image size (at 4X, nm)	260	220	160
Minimum OPC size (opaque 4X, nm)	130	110	80
Mask image placement technology	21	19	16
Mask CD metrology tool precision (P/T=0.2 for isolated lines, binary)	1.3	1.1	0.7
Mask CD metrology tool precision (P/T=0.2 for isolated lines, alternated)	1.75	1.6	1.15
Mask CD metrology tool precision (P/T=0.2 for dense lines, binary)	1.6	1.45	0.85
Mask CD metrology tool precision (P/T=0.2 for contact/vias)	1.2	1.05	0.65
Phase metrology precision (P/T=0.2)	0.4	0.4	0.2

157nm Wavelength Aerial Image Measurement System

Zeiss AIMS157



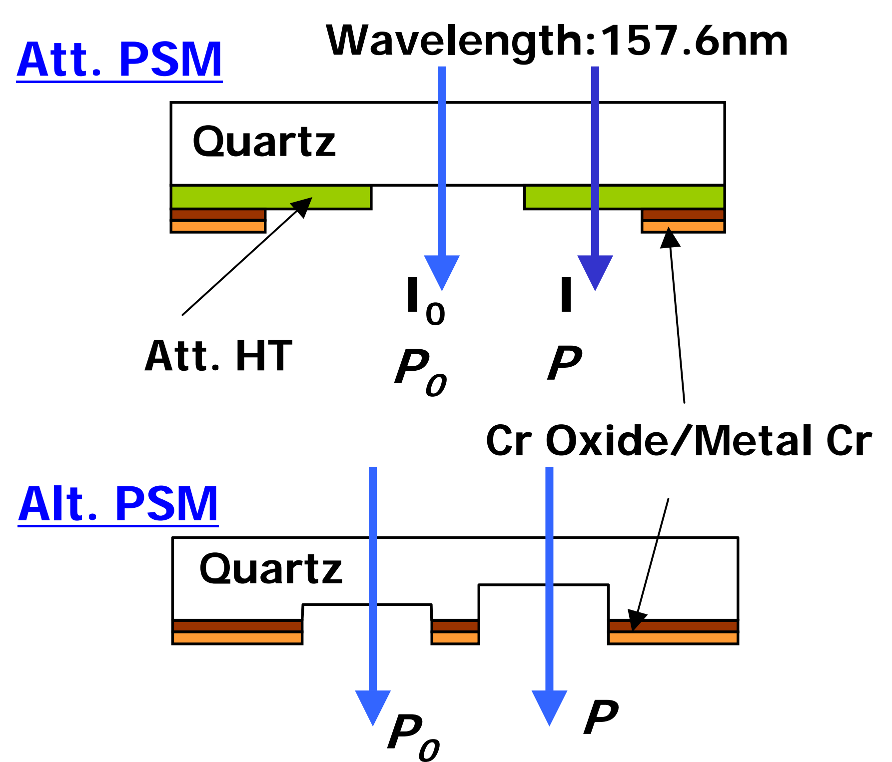




AIMS157 beta-tool

157nm Wavelength Mask Phase Measurement

Lasertec MPM157



Phase Sift= $P - P_0$, T%= I/I_0

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EPL mask defect inspection

Photo mask
6mm
100nm
Quartz

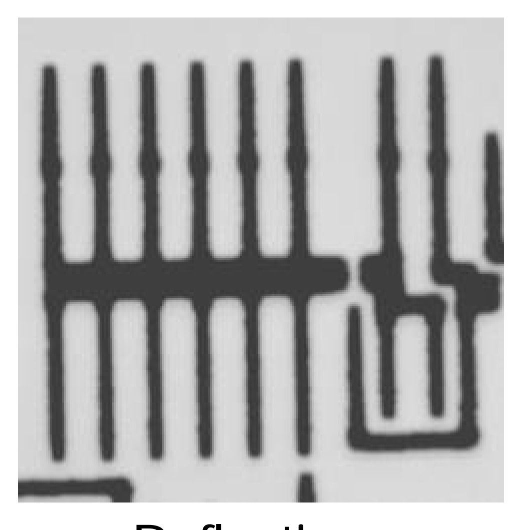
EPL
1.13mm
Strut
2μm
Si

Defect

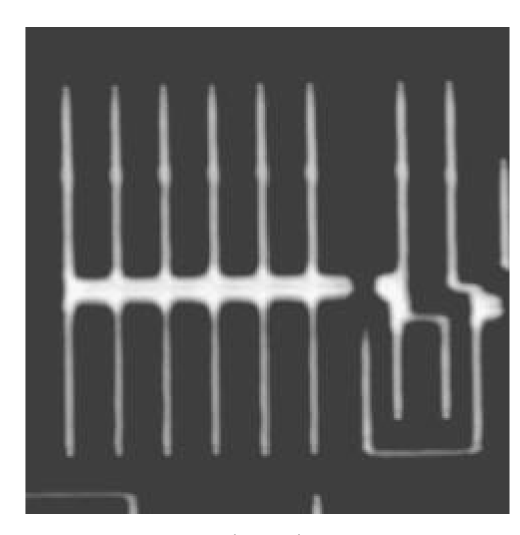
	Photo mask	EPL Mask
Magnification	4 x	4 x
Pattern Thickness	100 nm	2000 nm
Pattern Aspect Ratio *	Low (0.5)	High (7)
Structure	2 Dimensional	3 Dimensional
Substrate	Thick and Firm	Thin and Fragile
Pattern Material	Metal (Cr)	Si
Pattern Support	Exist (Quartz)	None (Strut)

*: 260nm (4x)

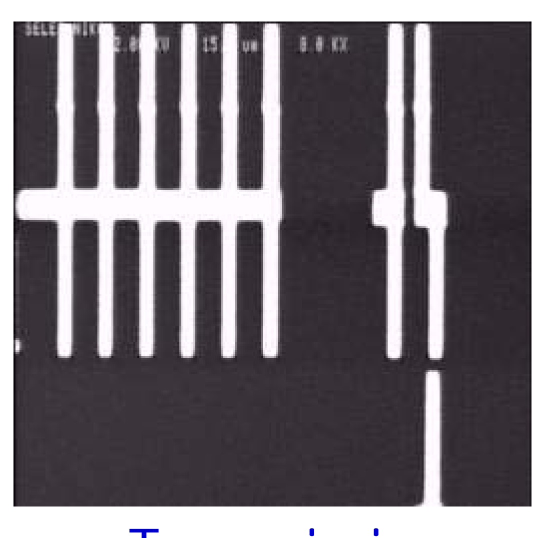
Inspection image for EPL mask (Optical vs SEM)



Reflection



Transmission



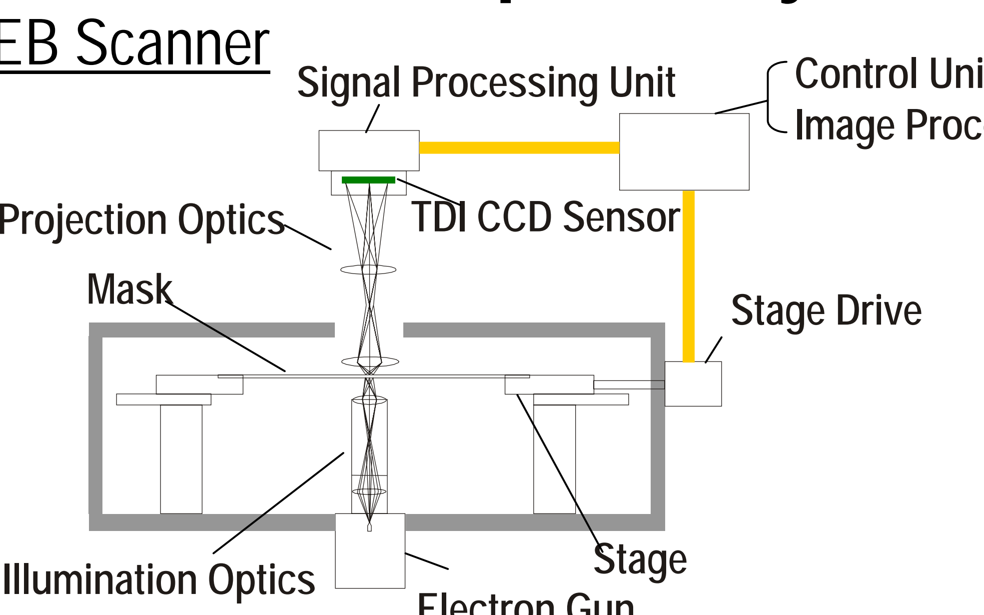
Transmission

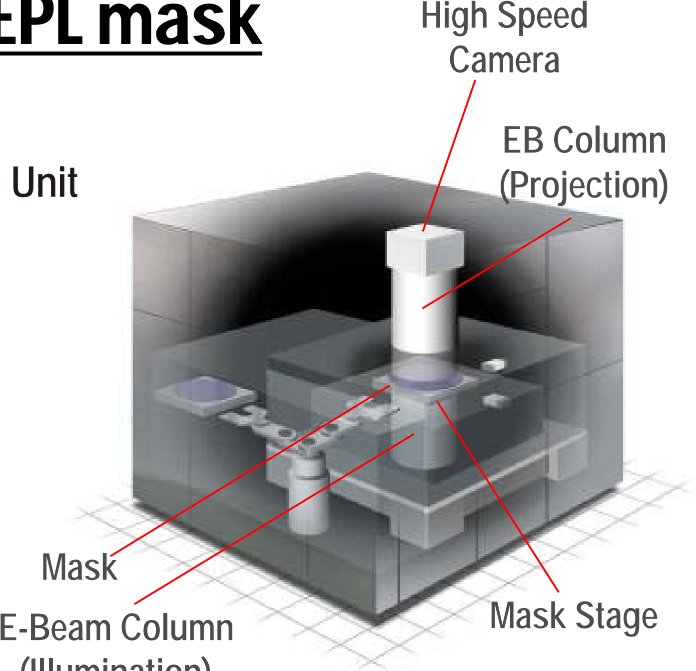
DUV Optical Microscope (Wavelength : 266nm)

SEM (HOLON EST-100)

EB inspection system for EPL mask

EB Scanner





Machine Specification

Mask	Stencil mask
Scan	Stage Scan
Alignment	Optical & EB
Mask Loading	Palette
Inspection Mode	Die to Database & Die to Die
Pixel Size	50 nm
Acceleration Voltage	5 kV
Throughput	4.6 h (200-nm EPL mask)

TDI-CCD Image with EB inspection system

70-nm node logic pattern

8 um
560 nm
280 nm

Design : 280 nm on mask

TDI-CCD Image with EB inspection system

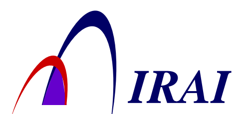
100-nm node DRAM pattern

20 um

800 nm

360 nm

Design : 360 nm on mask



EUV mask & process

1: Substrate clean

2: Multilayer (Si/Mo) Deposition

EUV microscope, EUV defect detection tool?

3: Buffer layer / Absorber layer Deposition

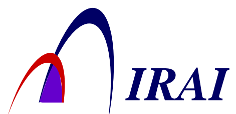
4: Pattern Write / Absorber etch

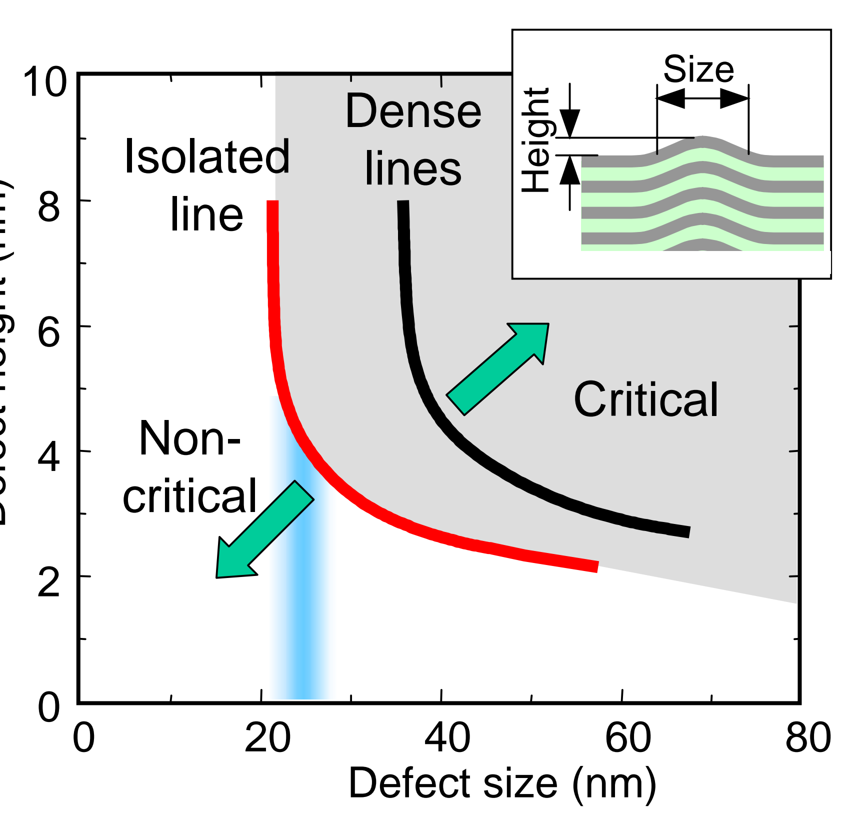
5: Repair / Buffer layer etch

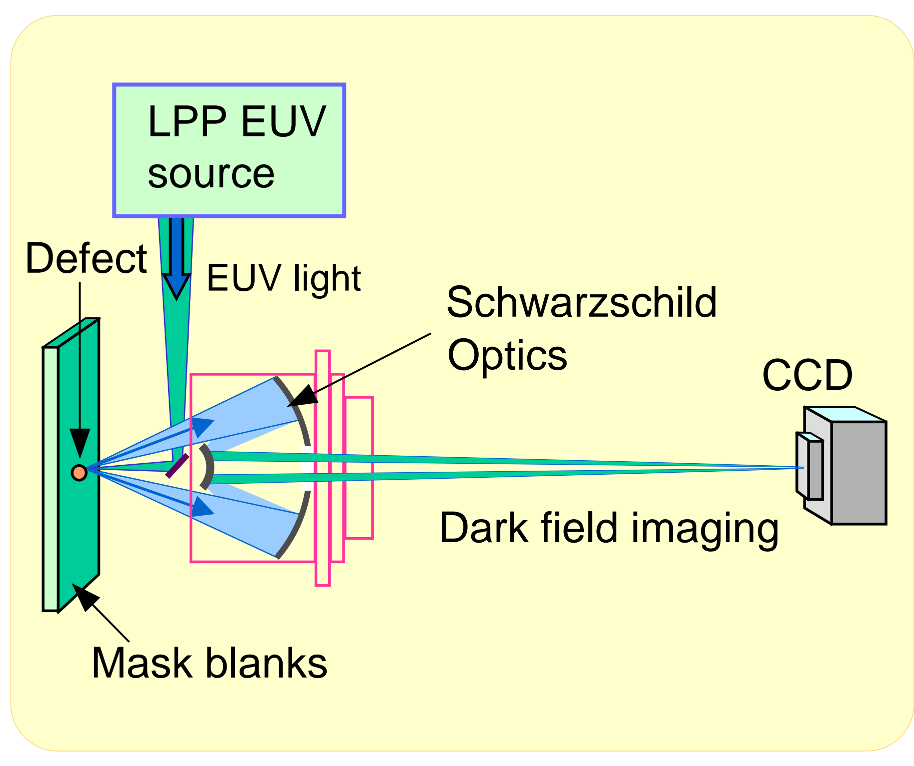
EUV AIM

Possible market for actinic (at-wavelength) inspection

EUV mask phase defect inspection







Summary

- The minimum feature size of ULSI devices becomes smaller than wavelength of exposure light used in optical lithography.
- The mask technology such as OPC and PSM with the current large NA projection exposure tool provides the fine features with approximately a half of exposure wavelength. Since a mask is the original edition of semiconductor patterns, precise control of the mask aperture size becomes critical.
- The requirements of mask pattern defects also becomes critical. In order to achieve the higher defect sensitivity, the defect inspection tools with UV(266nm) / DUV(198nm) laser are developed.
- CW-deep UV laser source for mask inspection tool has been developed.
- As 157nm mask metrology tool, aerial image monitor tool and phase measurement tool are developed.
- Inspection technologies for EPL and EUVL mask are under development.
  - EPL mask: EB imaging system
  - EUV mask: At-wavelength phase defect detection system.