Grid correction methodology for EUV mask

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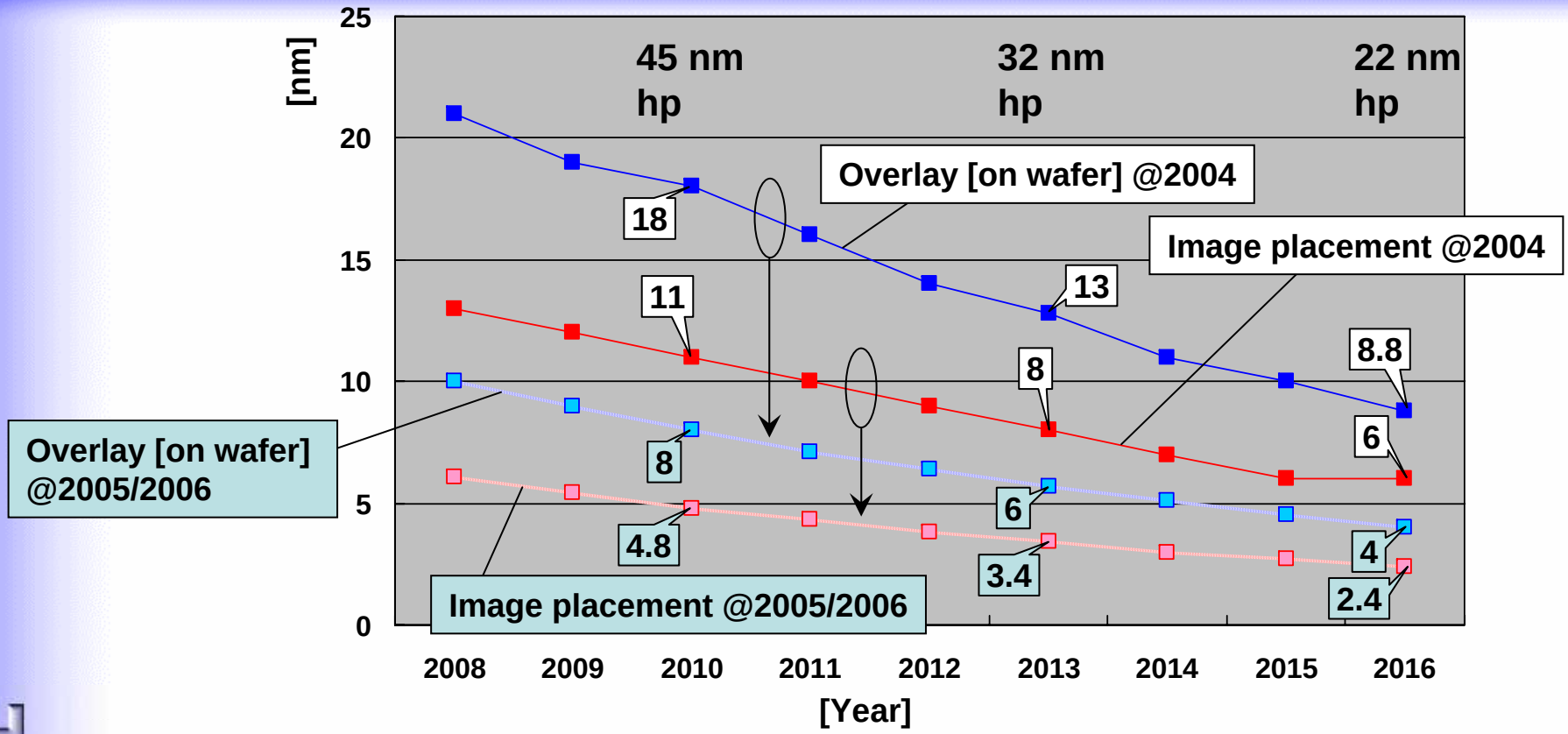
* *Grid Matching Correction for Thickness Variation*
** *Offline Blank Backside Topography Correction*

1-1. Overlay and IP requirement in ITRS roadmap



- EUV lithography was considered for the volume production of 32 nm hp devices.
- Extended use of evolving optical lithographic technologies and challenging of EUV specific issues are pushing out the timing of EUV adoption to 22 nm hp.

1-2. Challenges of IP requirement for EUV mask

- IP requirement
  - IP requirement for EUV mask is the same as that for optical mask as shown in ITRS roadmap.
    - Mix & Match with ArF scanner
- Issues for EUV specific IP errors
  - Electro-Static Chuck (ESC)
  - Mask non-flatness
  - Criteria to define IP accuracy
    - No IP standard with ESC
    - Measurement procedure and definition of IP accuracy are unclear.

1-3. IP error analysis of EUV mask

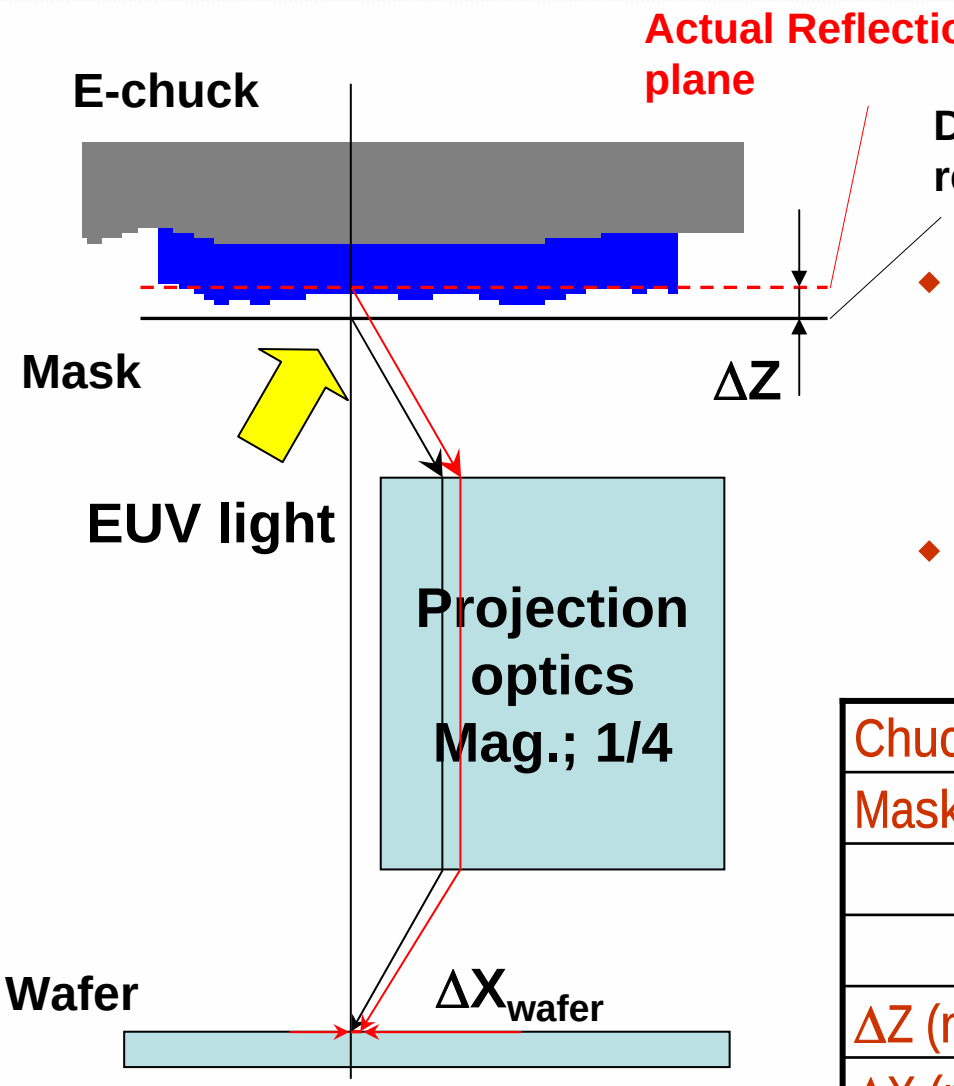
Requirement on ITRS	2008	2010	2013	2016
DRAM half pitch (nm)	57	45	32	22
IP (nm, multipoint)	6.1	4.8	3.4	2.4
Blank flatness	75	50	32	23
Mask flatness error	12.2	9.0	6.9	6.1
Mask local slope	0.1	0.1	0.1	0.1
Mask deformation by film stress	~	~	~	~
Mask deformation by chucking	6.6	6.6	6.6	6.6
Sub total of specific error for EUV mask	13.9	11.1	9.6	9.0

- IP requirement is very tight, while IP errors caused by EUV specific characteristics are significantly large.
- *One of the solutions; GMC-TV (former OBBTC)*
- Provision for successful correction by GMC-TV; ESC can chuck EUV mask completely with good reproducibility.

1-3-1. Non-telecentricity and mask shape

- EUV light is obliquely projected onto the mask, and reflected at angle of 6 degree.
- IP errors induced by mask non-flatness
  - The location of EUV light projected onto a wafer will be changed by actual reflection plane on the mask.
- IP errors induced by mask local slope
  - The local slope on the mask will change the reflection angle of EUV light.

1-3-2. IP errors induced by mask non-flatness



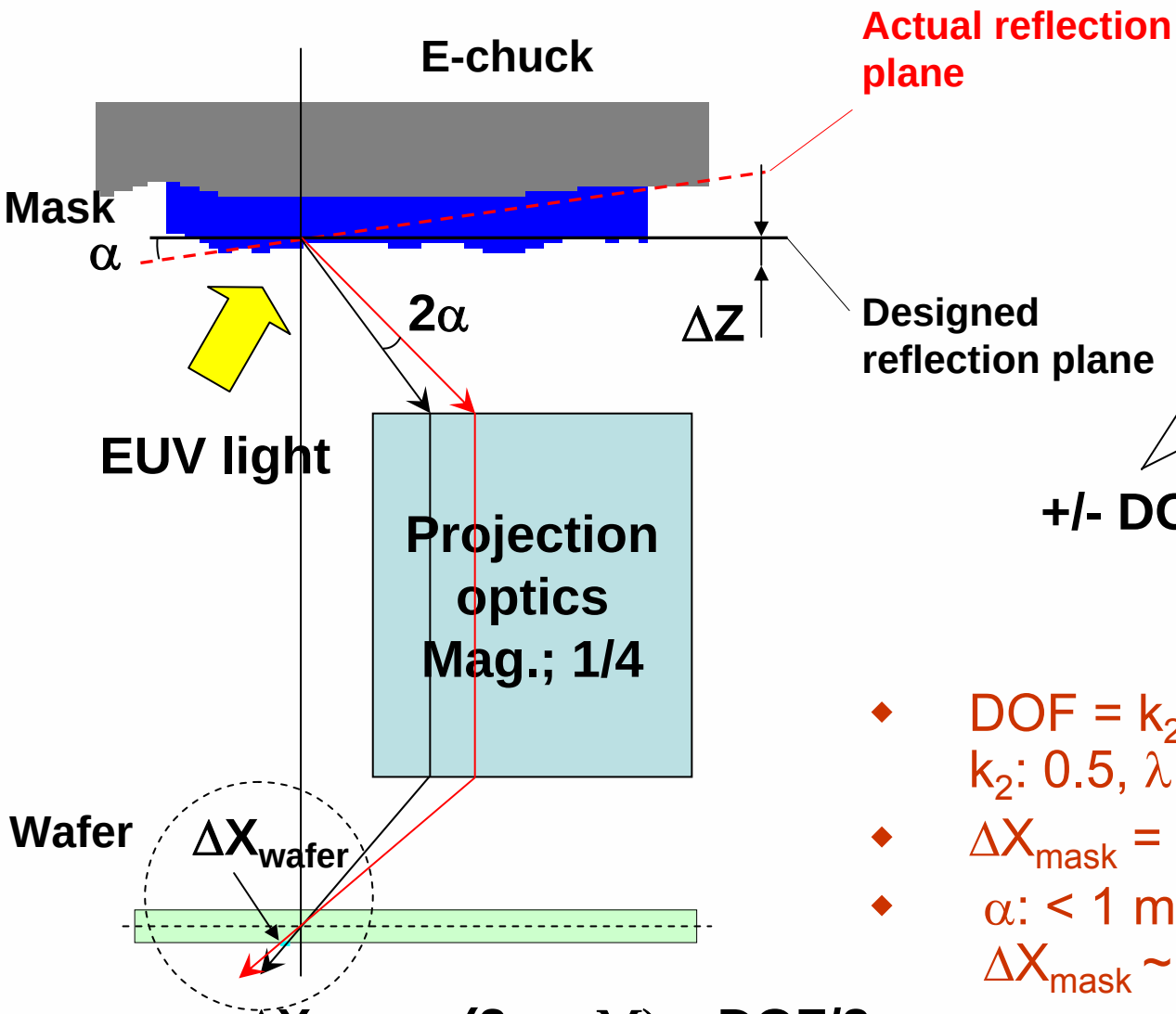
$\Delta X_{wafer} = M \times \Delta Z \times \tan\theta$

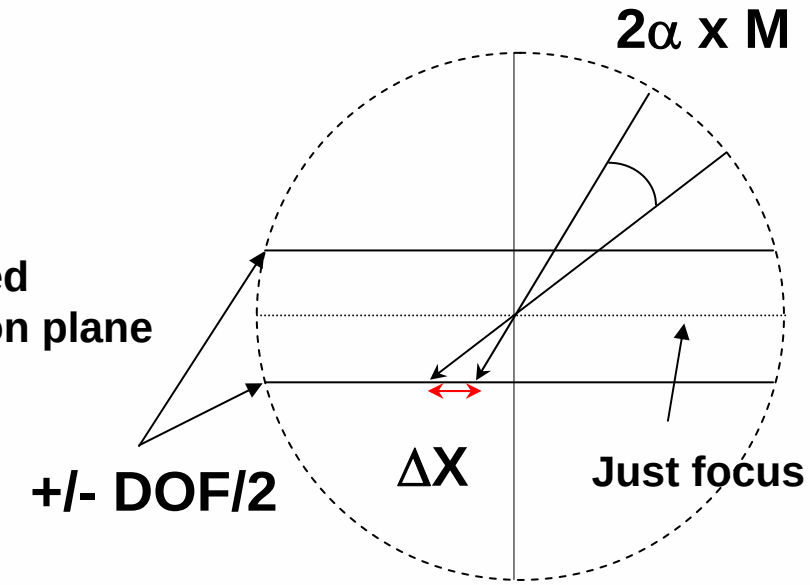
- $\Delta X_{mask} = (1/M) \times \Delta X_{wafer}$
  $\Delta X_{mask} = \Delta Z \times \tan\theta$
  $\theta = 6$ degree
  $\Delta X_{mask} = 0.11 \times \Delta Z$
- $\Delta Z = (\Delta Z_{chuck}^2 + \Delta Z_{mask_frontside}^2 + \Delta Z_{mask_backside}^2)^{0.5}$

Chuck surface	48 nm			
Mask flatness (nm)				
Front side	75	50	32	23
Back side	75	50	32	23
ΔZ (nm)	116.4	85.5	66.0	58.0
ΔX (nm)	12.2	9.0	6.9	6.1

Mask thickness variation was not counted.

1-3-3. IP errors induced by mask local slope





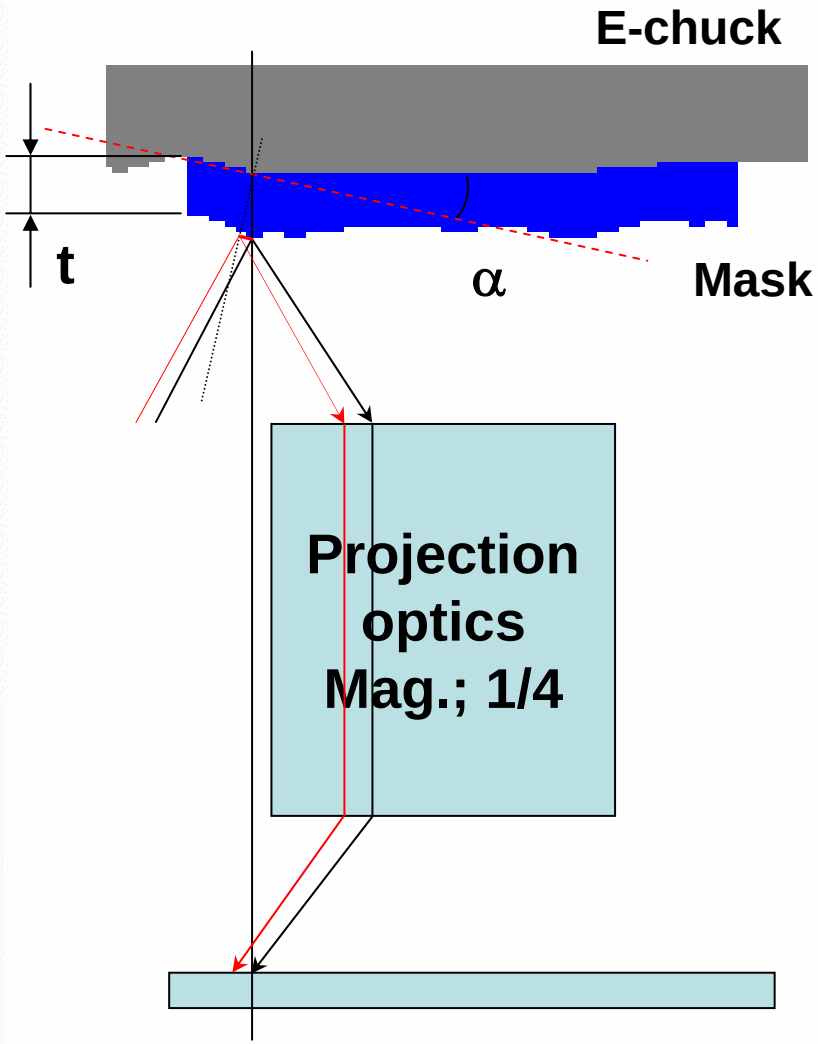
$\Delta X_{wafer} = (2\alpha \times M) \times DOF/2$

- DOF = $k_2 \times \lambda / NA^2 \sim 108$nm
  k_2: 0.5, λ: 13.5nm, NA: 0.25
- $\Delta X_{mask} = (1/M) \times \Delta X_{wafer}$
- α: < 1 mrad
  $\Delta X_{mask} \sim 0.1$ nm

1-3-4. Mask deformation

- Mask deformation induced by chucking
- Mask deformation induced by film stress
  - Absorber etching
    - +/- 3.9nm by +/- 200MPa stress variation
  - Multi-layer stress (ML) variation
    - +/- 0.2nm by +/-10% stress variation
  - Mask bow by ML film stress
    - 1 mm bow by ML film stress of 400MPa
  - Those properties of EUV mask should be improved through the untiring efforts of mask blank supplier.

1-3-5. Mask deformation induced by chucking



$\Delta X_{wafer} = M \times \alpha \times t$

- $\Delta X_{mask_chuck} = t \times \delta x/\delta z = t \times \alpha$

  Plate thickness; t = 6.35 mm

  Local slope on the mask;

  α = 1 μrad (backside)

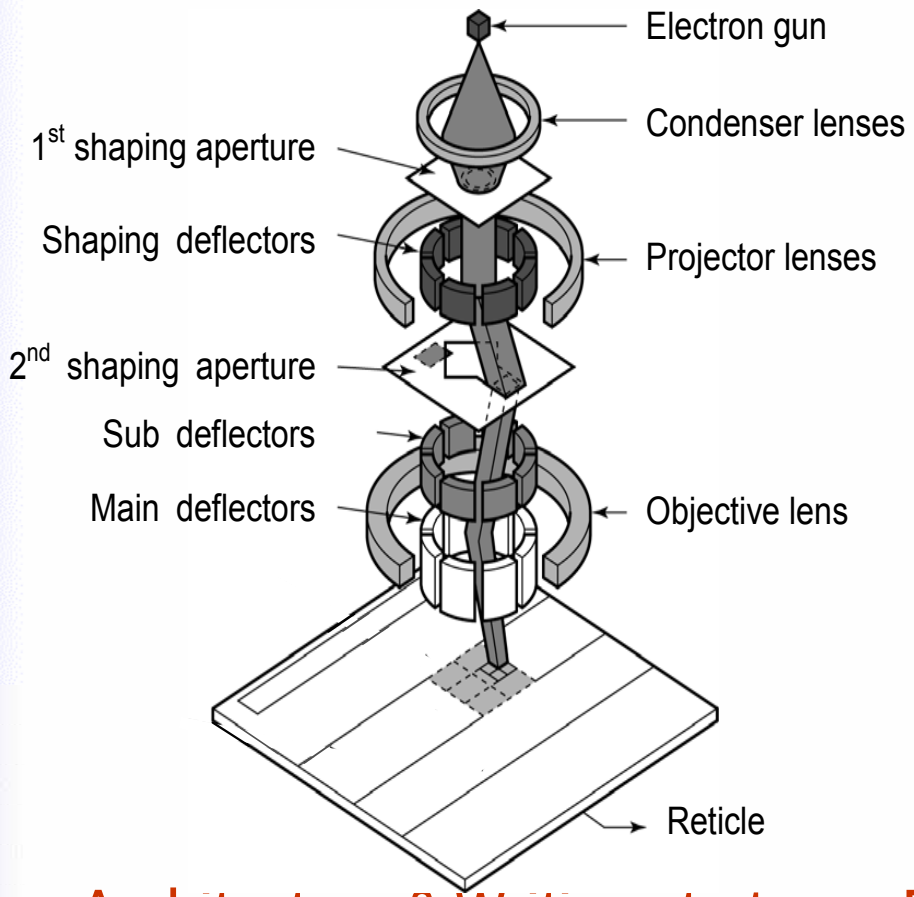
  Local slope on the chuck;

  α = 0.3 μrad (Pin: 3nm/10mm)

	Mask Holding Method				
EB writer	ESC1	ESC1	3PS	3PS	3PS
Metrology	ESC1	ESC2	ESC1	ESC1	3PS
Scanner	ESC1	ESC3	ESC1	ESC2	ESC
IP error (nm)	6.63	11.48	6.63	9.38	6.63

2-1. EBM-6000 basic features

System Architecture



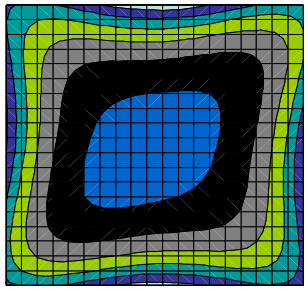
Acceleration voltage	50 kV
Current density	70 A/cm^2
Cathode	LaB_6
Maximum beam size	0.8 μm square
Main deflection field size	512 μm
Sub deflection field size	32 μm
Standard input data	VSB-12
Data address unit	0.1 nm ~ 100 nm (0.1nm or 0.25nm increment)
Image placement accuracy	8 nm (3σ)
Local CD uniformity	2.5 nm (3σ, divided shot)

- Architecture & Writing strategy : Based on EBM-5000
  - 50 kV Variable Shaped electron Beam (VSB)
  - Vector scan and continuous motion stage
  - Input data format : VSB-12

J. Yashima, et al., "Electron-beam mask writer EBM-6000 for 45 nm HP node", Proc. SPIE 6607

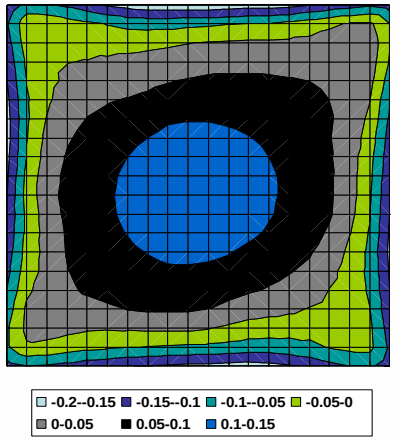
2-2. OBBTC

1. Obtain the blank backside topography using flatness measurement tool
2. Derive local gradient from the blank backside topography
3. Derive local pattern shift from local gradient map
4. Derive the coefficients of 3rd order polynomials for EB system
5. Add new coefficients to system parameters for each patterning job

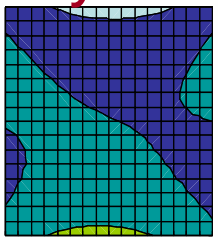


4th order polynomials fitting

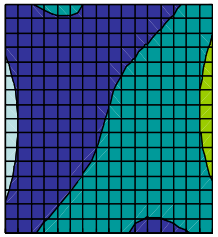
Plate 1

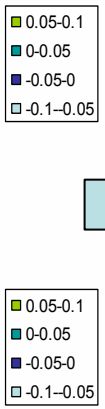


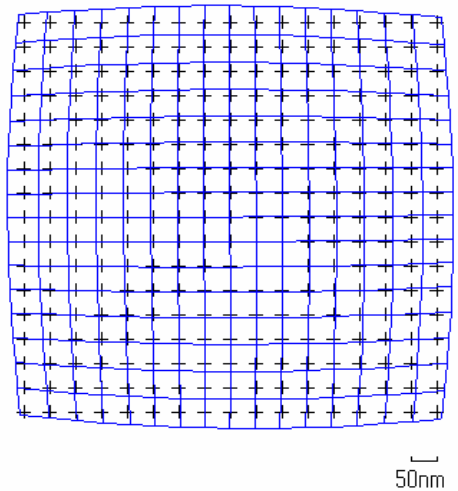
X_1



Y_1







X :			
mean	0.0	3s	33.9
max	32.7	min	-31.1
Y :			
mean	0.0	3s	37.4
max	33.8	min	-34.3

Xpitch:	0.2301	[ppm]
Ypitch:	0.2659	[ppm]
Ortho:	-0.0017	[10-5rad]
Rotate:	0.0005	[10-5rad]

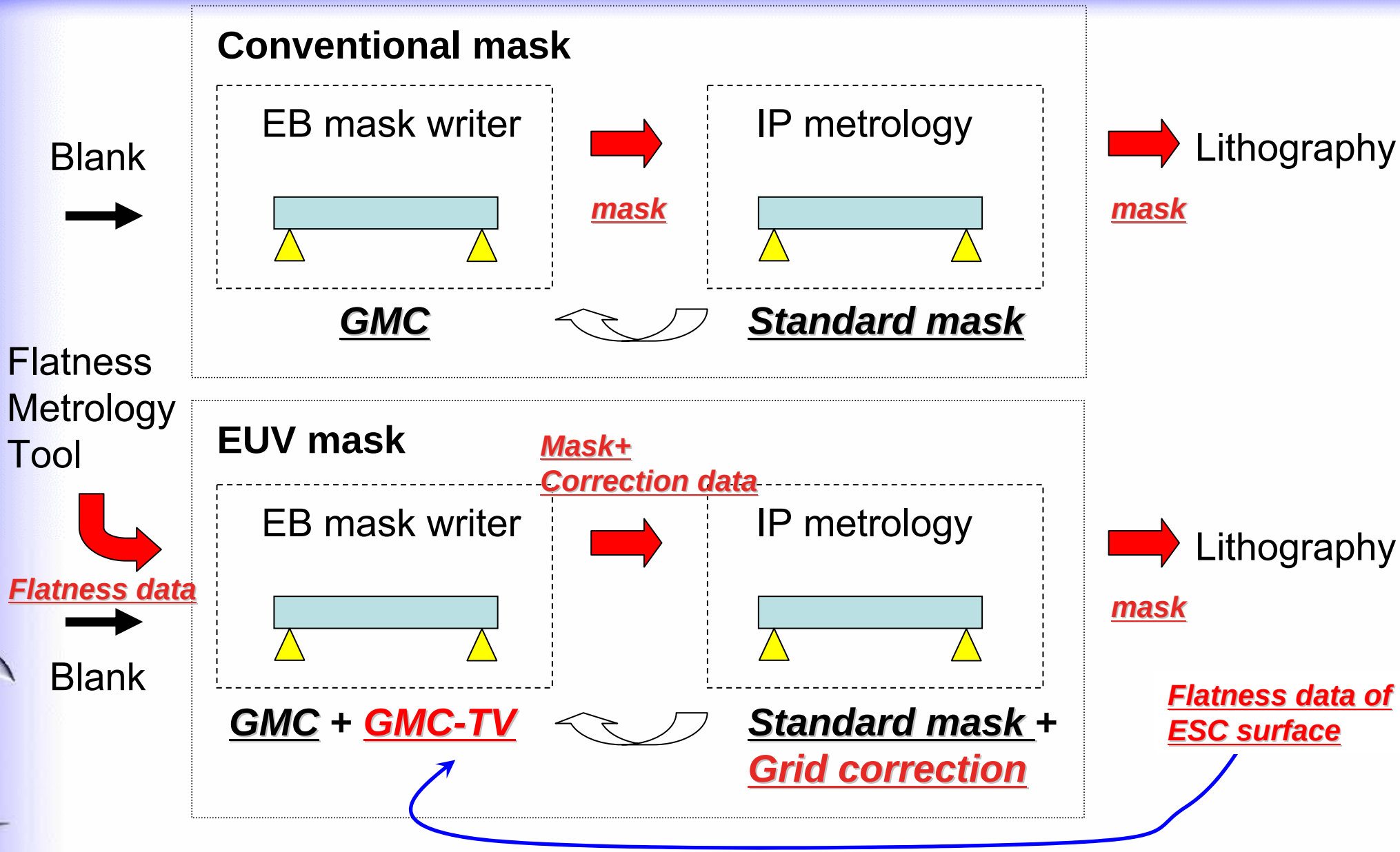
MODE:	CLEAR	LINEAR:	No
SHIFT:	Yes	MIRROR:	No
ALIGN:	No	3rd:	No
SCALE:	No	4th:	No

$$x_1 = a_{10}+a_{11}x+a_{12}y+a_{13}x^2+a_{14}xy+a_{15}y^2+a_{16}x^3+a_{17}x^2y+a_{18}xy^2+a_{19}y^3$$
$$y_1 = b_{10}+b_{11}x+b_{12}y+b_{13}x^2+b_{14}xy+b_{15}y^2+b_{16}x^3+b_{17}x^2y+b_{18}xy^2+b_{19}y^3$$

$$X_1 = (a_{s0}+a_{10})+(a_{s1}+a_{11})x+(a_{s2}+a_{12})y+(a_{s3}+a_{13})x^2+(a_{s4}+a_{14})xy+(a_{s5}+a_{15})y^2+(a_{s6}+a_{16})x^3+(a_{s7}+a_{17})x^2y+(a_{s8}+a_{18})xy^2+(a_{s9}+a_{19})y^3$$
$$Y_1 = (b_{s0}+b_{10})+(b_{s1}+b_{11})x+(b_{s2}+b_{12})y+(b_{s3}+b_{13})x^2+(b_{s4}+b_{14})xy+(b_{s5}+b_{15})y^2+(b_{s6}+b_{16})x^3+(b_{s7}+b_{17})x^2y+(b_{s8}+b_{18})xy^2+(b_{s9}+b_{19})y^3$$

S: system parameter for LMS-IPRO grid

2-3. Proposal of IP qualification flow for EUV mask



3-1-1. Experiment (1)

Residual errors of surface fitting were examined with samples of photomask.

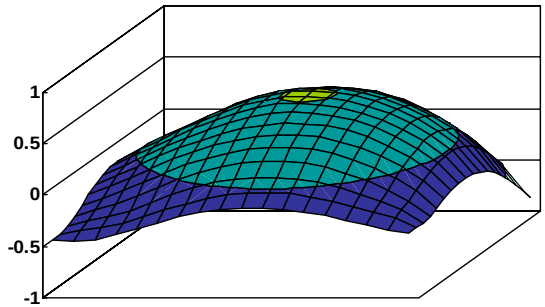


Plate 1: 1.590 μm

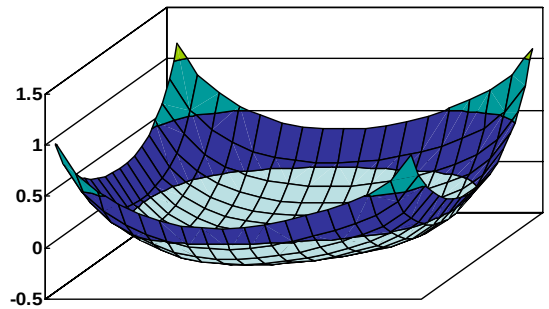


Plate 2: 1.795 μm

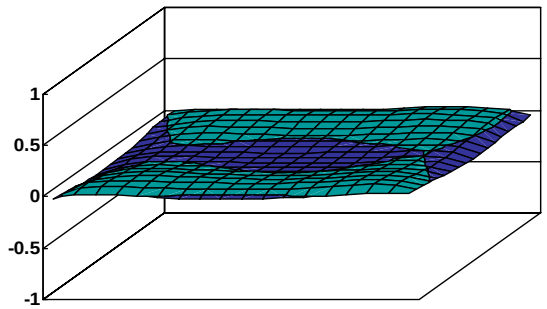


Plate 3: 0.200 μm

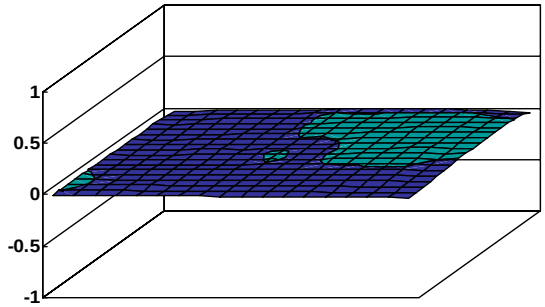


Plate 4: 0.130 μm

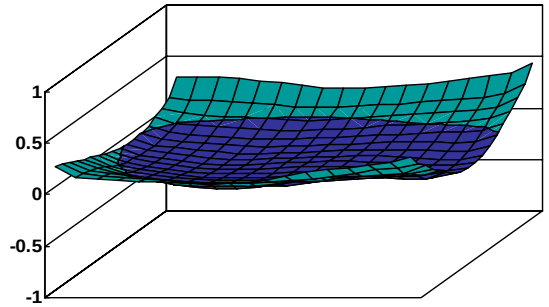


Plate 5: 0.731 μm

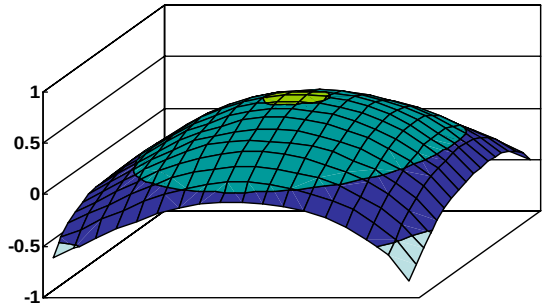
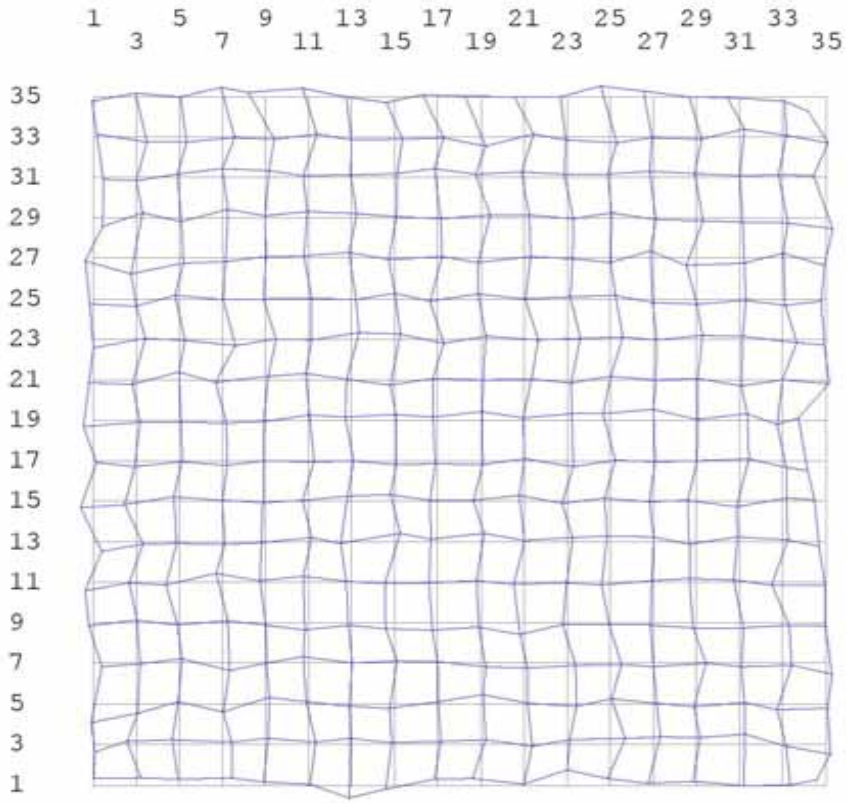


Plate 6: 0.639 μm

Topography data and blank materials were prepared by HOYA.

3-1-1. Experiment (1)

Measured by LMS-IPRO



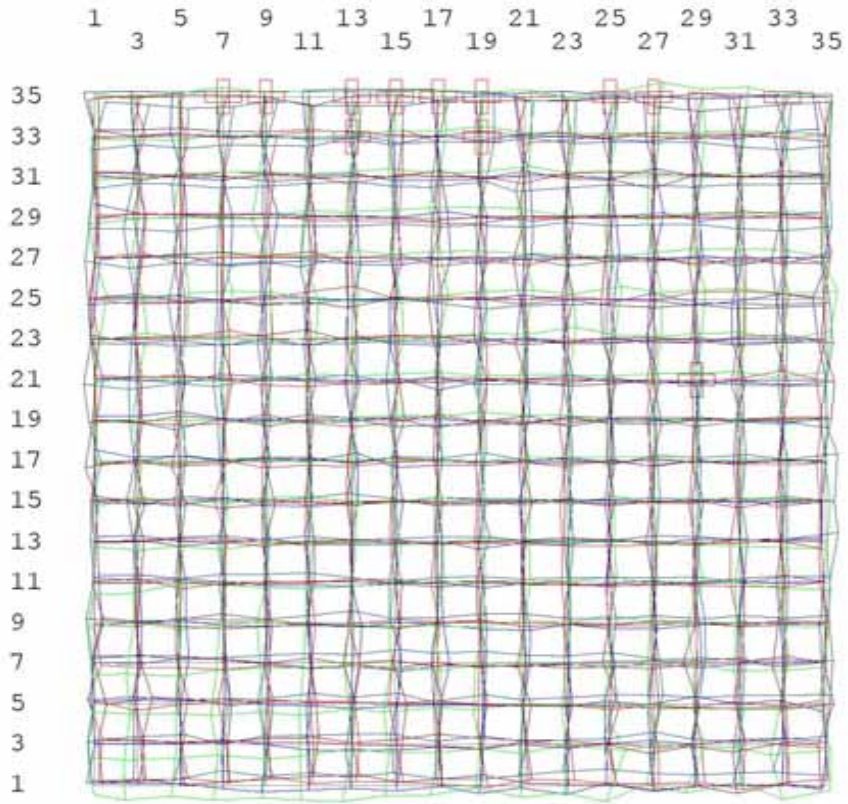


	Image placement accuracy		Image placement repeatability	
	X [nm]	Y [nm]	X [nm]	Y [nm]
3 σ	***6.05***	***5.09***	***4.89***	***6.73***
Max	4.92	5.04	5.04	5.38
Min	-8.84	-6.71	-4.68	-5.89

3-1-1. Experiment (1)

Corrected EB grid | **IPRO measurement** | **Comparison**

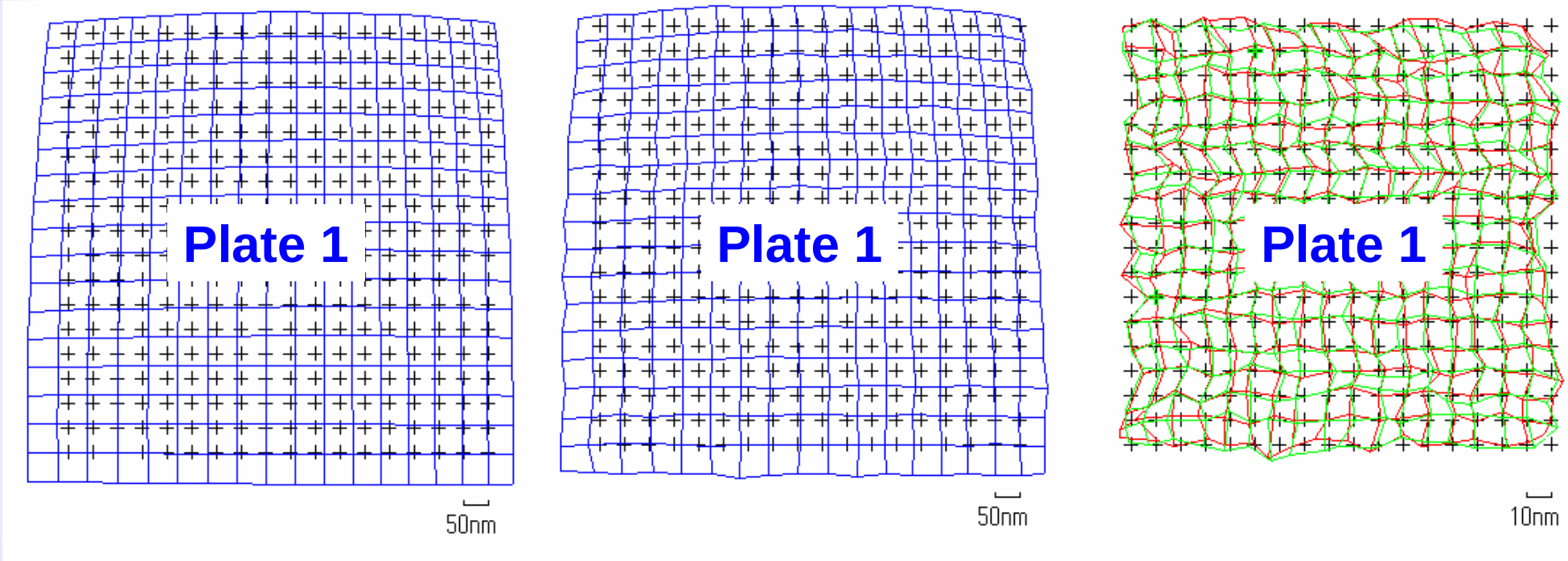


	Image Placement Accuracy (nm)					
	Corrected EB grid		IPRO measurement		Comparison	
	X	Y	X	Y	X	Y
3 σ	108.7	95.9	104.1	93.1	8.6	6.0
Max	51.5	-81.5	55.9	42.3	9.4	5.4
Min	41.6	-66.4	-78.1	-67.7	-10.4	-7.4

3-1-1. Experiment (1)

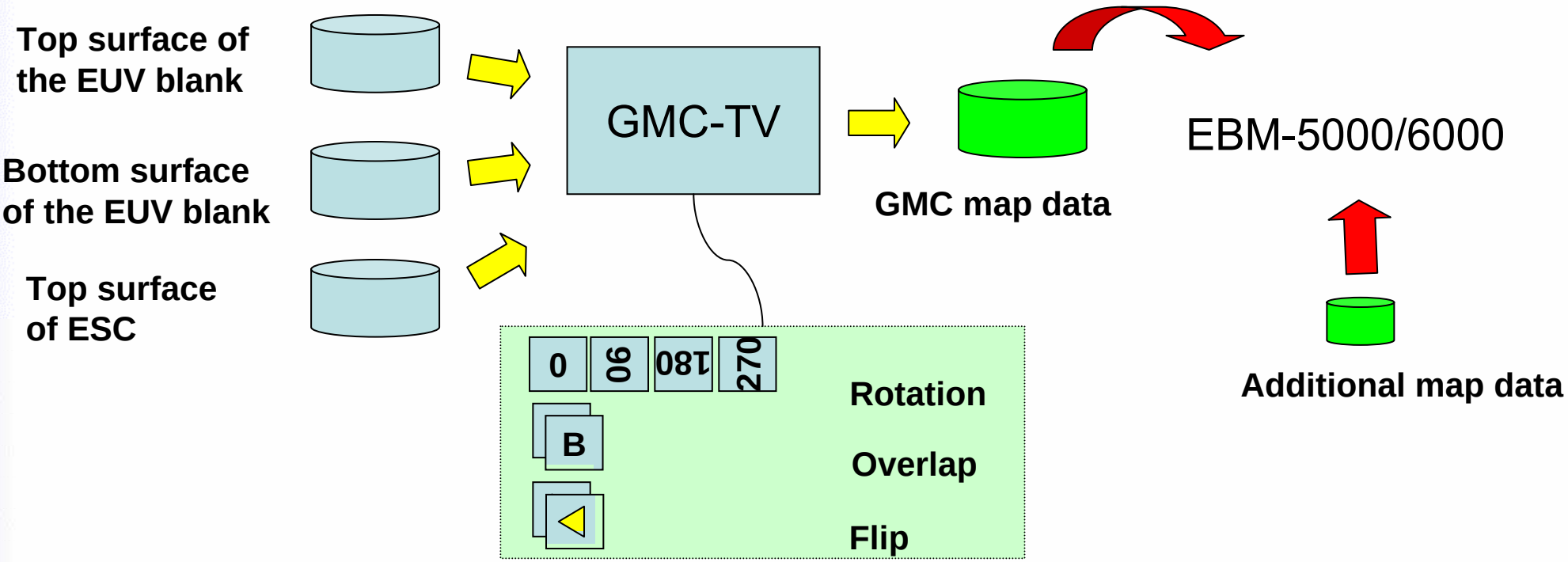
	IP accuracy without OBBTC [3s (nm)]		IP accuracy with OBBTC measured by LMS-IPRO [3s (nm)]		IP accuracy with OBBTC measured by LMS-IPRO based on corrected EB grid [3s (nm)]	
	X	Y	X	Y	X	Y
Plate 1	5.7	5.7	104.1	93.1	*8.6*	*6.0*
Plate 2	6.3	5.8	164.0	154.7	*7.1*	*6.7*
Plate 3	6.7	6.3	23.9	18.3	*7.4*	*7.0*
Plate 4	7.5	6.0	9.6	6.8	*6.9*	*6.1*
Plate 5	5.7	5.7	34.2	72.6	*7.7*	*7.0*
Plate 6	5.9	5.5	108.7	92.9	*6.9*	*6.6*

- There are no significant errors caused by OBBTC.
  - Residual errors of IPA and IPR of EBM-5000 with OBBTC were comparable to IPA and IPR without OBBTC.
  - The writing grid of EBM-5000 was successfully corrected to the assigned grid by OBBTC.

3-1-2. Experiment (2)

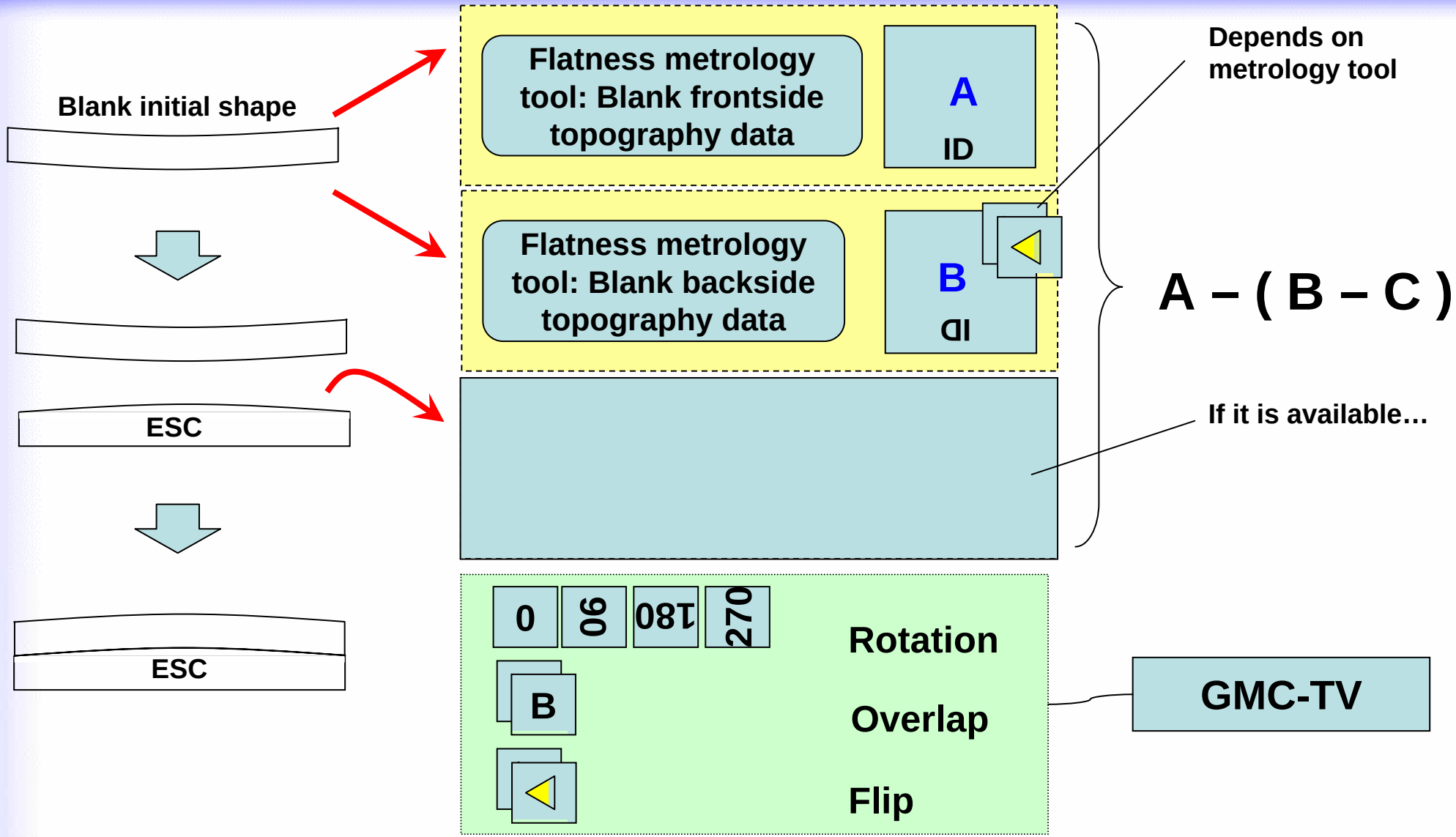
S. Yoshitake, et al., "Correction technique of EBM-6000 prepared for EUV mask writing", Proc. SPIE 6730

- GMC-TV (GMC for Thickness Variation)
  - Additional grid correction software based on the topographic data of top and bottom surfaces of EUV blank.



3-1-2. Experiment (2)

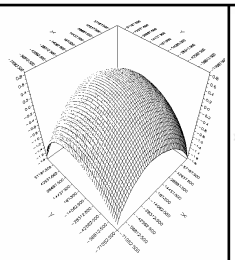
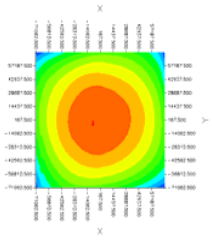
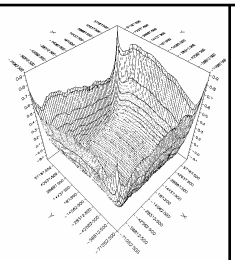
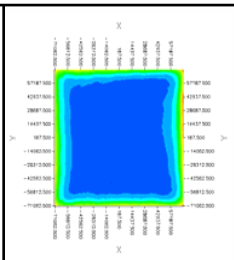
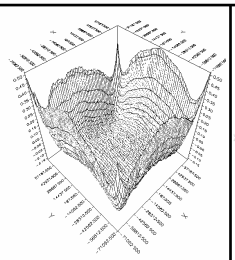
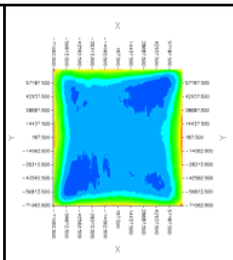
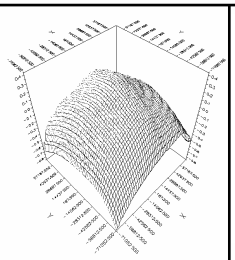
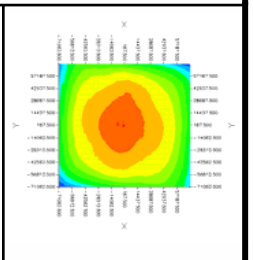
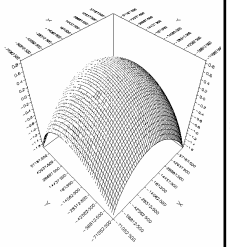
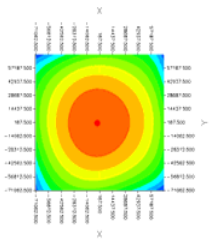
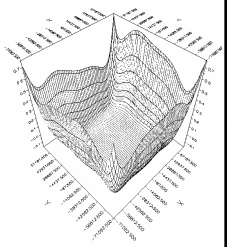
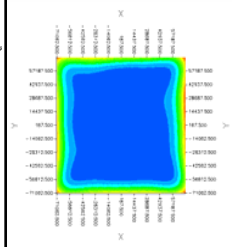
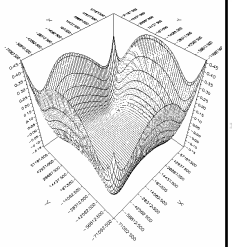
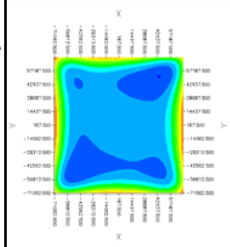
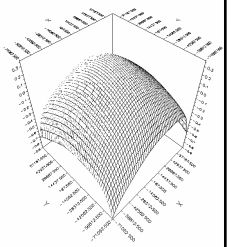
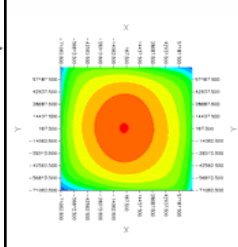
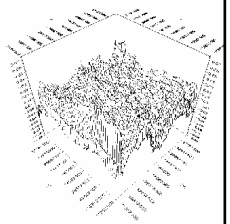
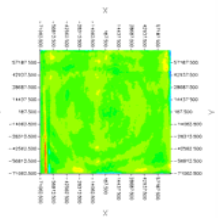
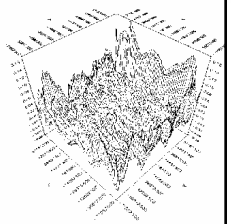
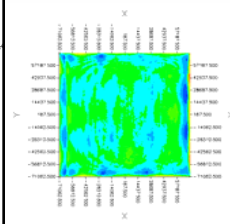
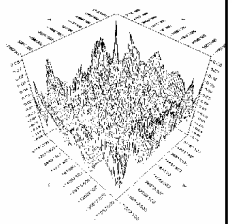
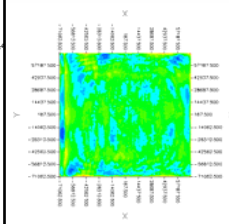
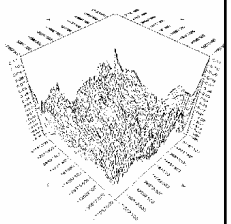
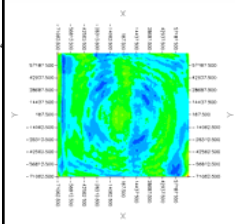
S. Yoshitake, et al., "Correction technique of EBM-6000 prepared for EUV mask writing", Proc. SPIE 6730



IP errors on top surface based on bottom surface and ESC surface can be counted except an isotropic errors of thickness variation.

3-1-2. Experiment (2)

S. Yoshitake, et al., “Correction technique of EBM-6000 prepared for EUV mask writing”, Proc. SPIE 6730

	Blank A P-V; 2.107 μm in 132mm squares		Blank B P-V; 0.440 μm in 132mm squares		Blank C P-V; 0.426 μm in 132mm squares		Blank D P-V; 1.035 μm in 132mm squares	
Initial data								
Fitting								
Deviation								

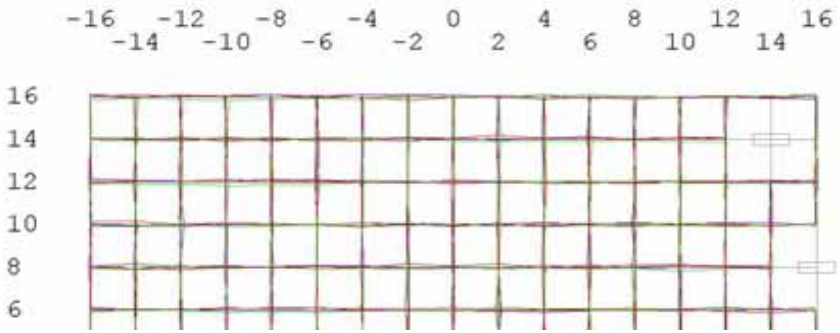
3-1-2. Experiment (2)

S. Yoshitake, et al., "Correction technique of EBM-6000 prepared for EUV mask writing", Proc. SPIE 6730

- **Deviation (3σ) of topography fitting in 132 mm square**
  - **Fitting errors of blank backside topography of photomask were less than 40 nm. It is acceptable for process development of EUV mask.**

	Order of polynomial equation	0.375 mm pitch (352-352 pixels)	1.498mm pitch (88-88 pixels)	2.996 mm pitch (44 pixels)
A	3	0.080	0.079	0.079
	4	0.040	0.040	0.038
	5	0.033	0.032	0.031
	6	***0.025***	***0.024***	***0.023***
B	3	0.170	0.170	0.167
	4	0.076	0.075	0.073
	5	0.075	0.074	0.072
	6	***0.033***	***0.032***	***0.030***
C	3	0.168	0.167	0.165
	4	0.058	0.057	0.056
	5	0.054	0.053	0.052
	6	***0.029***	***0.028***	***0.026***
D	3	0.093	0.093	0.092
	4	0.065	0.065	0.064
	5	0.064	0.064	0.063
	6	***0.038***	***0.038***	***0.036***

3-2-1. Study of chucking repeatability



Measurement repeatability of IP metrology tool with loading and unloading

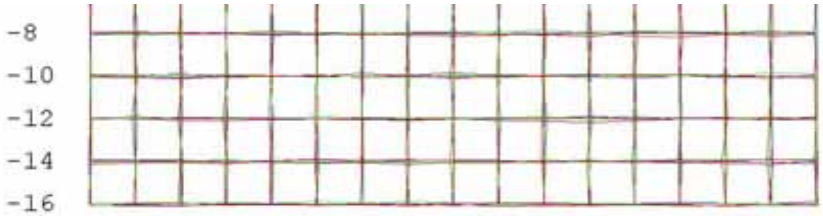
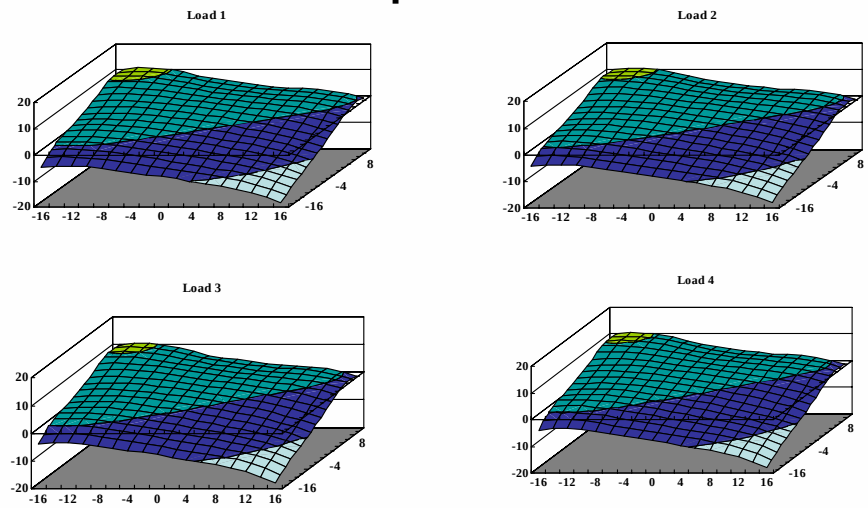
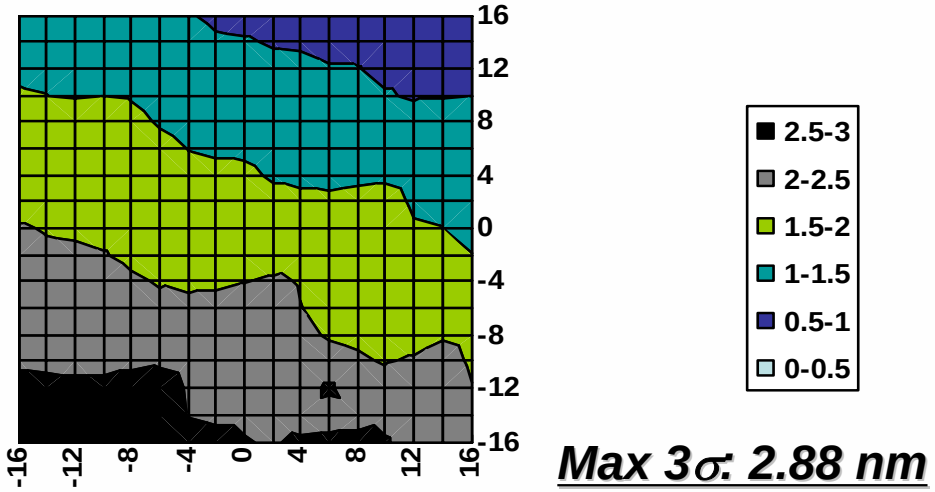


	Image placement repeatability	
	X [nm]	Y [nm]
3 σ	***1.24***	***1.61***
Max	1.36	1.26
Min	-1.13	-1.47

Focus variation map for each measurement



Focus variation map at each measurement point

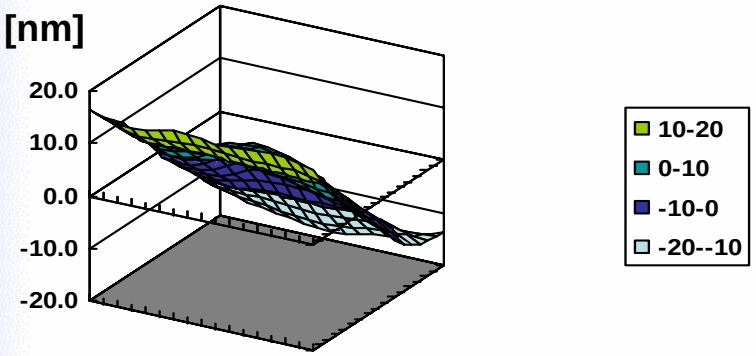


Max 3σ: 2.88 nm

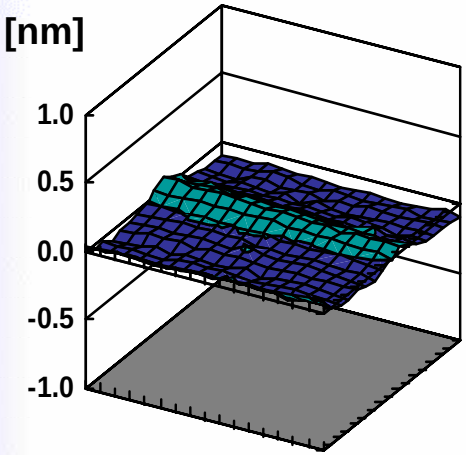
3-2-2. Study of chucking repeatability

Focal point map of IP metrology tool

Initial height map with flat chuck



Height differences between load1 and load2



Height differences between load2 and load3

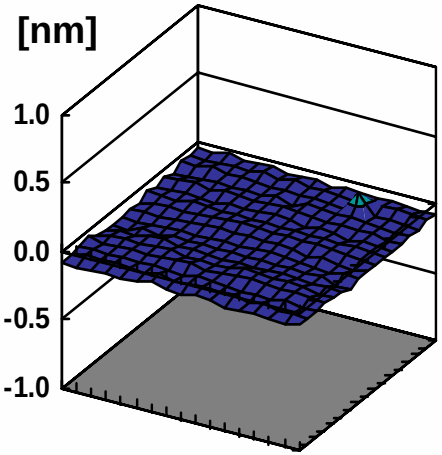
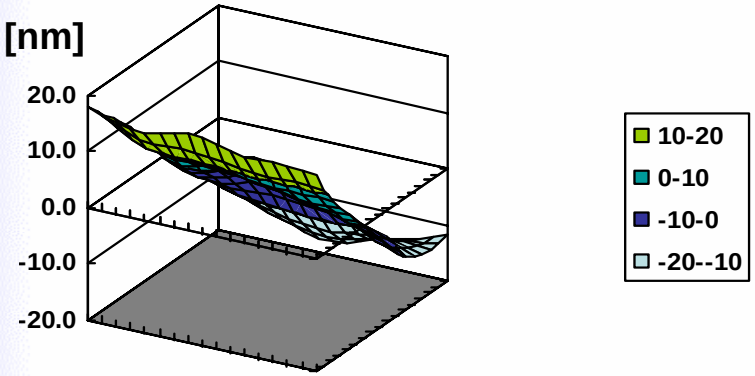


	Image placement repeatability	
	X [nm]	Y [nm]
3 σ	***1.49***	***1.81***
Max	0.76	1.53
Min	-1.53	-1.54

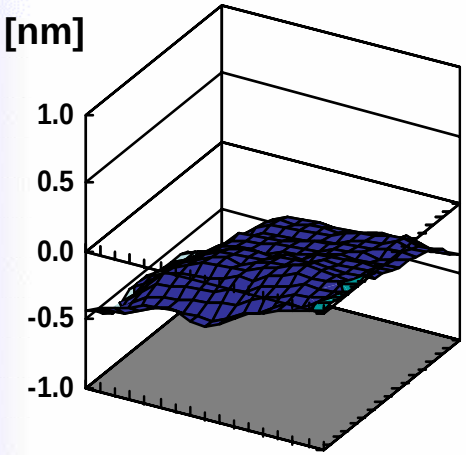
3-2-3. Study of chucking repeatability

Focal point map of IP metrology tool

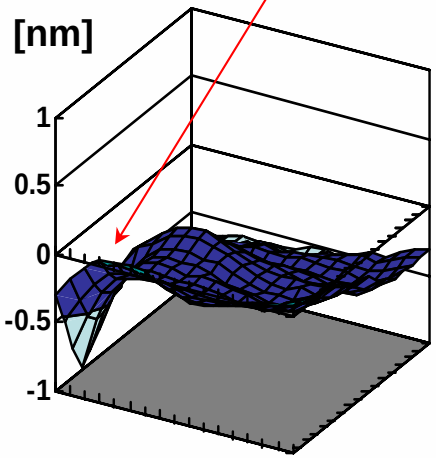
Initial height map with flat chuck

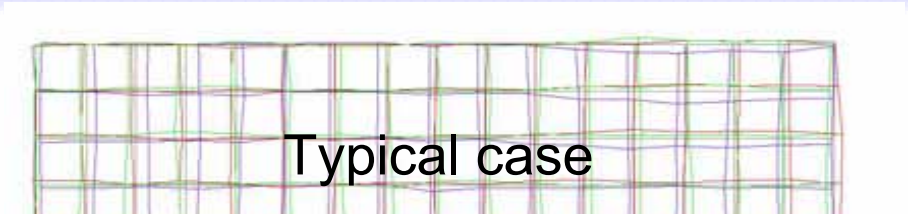


Height differences between load1 and load2



Height differences between load2 and load3





Local deformation results in large local slopes, and consequently gives large impacts to the reproducibility.

	Image placement repeatability	
	X [nm]	Y [nm]
3 σ	***11.26***	***5.84***
Max	11.40	10.29
Min	-18.33	-9.01

4. Conclusion

- IP errors specific to EUV mask are critical, and must be addressed at an early stage of process development for EUV lithography.
- Advanced grid matching correction, GMC-TV (former OBBTC) of EBM-6000, proved its certain practical functionality for EUV mask writing.
  - Residual error of GMC-TV could be neglected in case a flat mask was used as EUV blank.
- Proposed IP Qualification flow for EUV mask manufacturing is practical and applicable to current mask process with additional minimum cost.
- IP of test pattern was substantially affected by the variation of surface topography under the experimental conditions with vacuum chuck.

Acknowledgement

- We would like to thank Dr. Tsutomu Shoki of HOYA corporation for the blank flatness data and technical suggestions.
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