Progress of EUV blanks development

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Blanks division

Outline

1. EUV blanks history and progress
   - HOYA development history
   - EUV focus area trend

2. EUV blanks development: current status
   - HOYA's strength
   - Difficulties in EUV blanks
   - Current status

3. Summary

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Mask Blank is considered as a high risk item for EUV Lithography.

*The same message shown by Hoya, at the 8^{th} annual SEMATECH symposium in 2012.

EUV Focus Areas 2006-2010: 22 nm half-pitch insertion target

SEMATECH

2007 / 22hp	2008 / 22hp	2009 / 22hp	2010 / 22hp	2011 / 22hp
1. Reliable high power source & collector module	1. Long-term source operation with 100 W at IF and 5MJ/day	1. Mask yield & defect inspection/review infrastructure	1. Mask yield & defect inspection/review infrastructure	1. Long-term reliable source operation with 200 W at IF*
2. Resist resolution, sensitivity & LER met simultaneously	2. Defect free masks through lifecycle & inspection/review infrastructure	2. Long-term reliable source operation with 200 W at IF	1. Long-term reliable source operation with 200 W at IF	2. Mask yield & defect inspection/review infrastructure
3. Availability of defect free mask	3. Resist resolution, sensitivity & LER met simultaneously	3. Resist resolution, sensitivity & LER met simultaneously	2. Resist resolution, sensitivity & LER met simultaneously	3. Resist resolution, sensitivity & LER met simultaneously
4. Reticle protection during storage, handling and use	• Reticle protection during storage, handling and use	• EUVL manufacturing integration	• EUVL manufacturing integration	• EUVL manufacturing integration
5. Projection and illuminator optics quality & lifetime	• Projection / illuminator optics and mask lifetime			

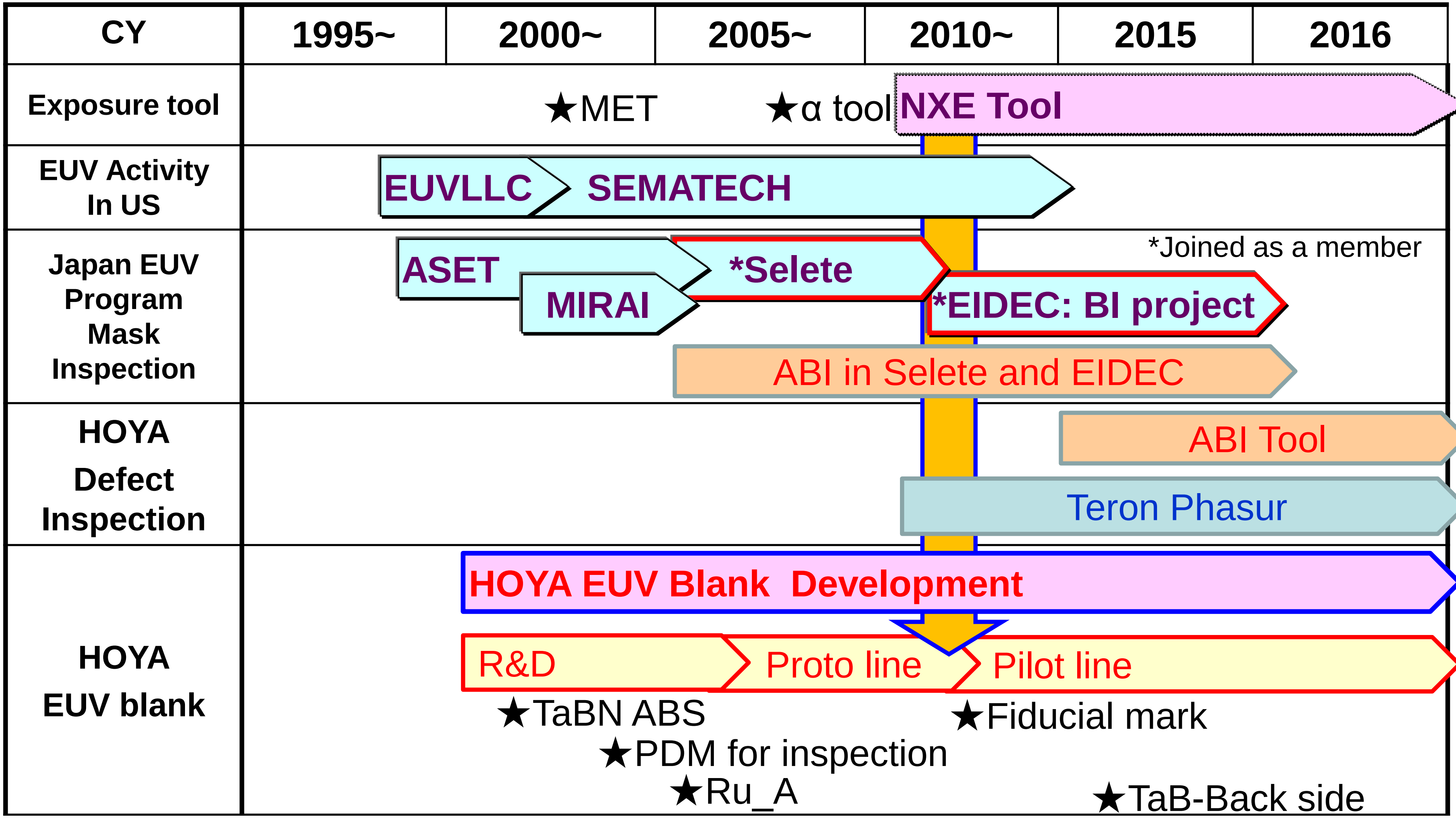
*) *This requires a 20 X improvement from current source power status*

EUVL

HVM introduction in late 2013 if productivity challenge can be met

30 October 2011 2011 EUVL Symposium 9

HOYA EUV Blanks Development History
Current Phase: CY2012~



- Focusing on blank development with high sensitivity inspection toward EUVL production

EUV Focus Areas 2006-2010: 22 nm half-pitch insertion target

2007 / 22hp	2008 / 22hp	2009 / 22hp	2010 / 22hp	2011 / 22hp
1. Reliable high power source & collector module	1. Long-term source operation with 100 W at IF and 5MJ/day	1. Mask yield & [illegible]ect inspectio[illegible] infr[illegible]	1. Mask yield & defect inspection/review infrastructu[illegible]	1. Long-term reliable source operation with 200 W at IF*
2. Resist resolution, sensitivity & LER met simultaneously	2. Defect fre[illegible] thr[illegible]ycle & [illegible]on/review [illegible]nfrastructure	2. Long-term reliable source operation with 200 W at IF	1. Long-term reliable source operation with 200 W at IF	2. Mask yiel[illegible] inspection/review infrastructure
3. Availabi[illegible]ect fr[illegible]	3. Resist resolution, sensitivity & LER met simultaneously	3. Resist resolution, sensitivity & LER met simultaneously	2. Resist resolution, sensitivity & LER met simultaneously	3. Resist resolution, sensitivity & LER met simultaneously
4. Reticle protection during storage, handling and use	• Reticle protection during storage, handling and use	• EUVL manufacturing integration	• EUVL manufacturing integration	• EUVL manufacturing integration
5. Projection and illuminator optics quality & lifetime	• Projection / illuminator optics and mask lifetime			

*) This requires a 20 X improvement from current source power status

HVM introduction in late 2013 if productivity challenge can be met

30 October 2011 2011 EUVL Symposium 9

EUVL FOCUS AREAS 2012-2015

2012 / 22hp	2013 / 22hp	2014 / 16hp	2015 / 16hp
1. Long-term reliable source operation with a. 200 W at IF in 2014 b. 500 W-1,000 W in 2016	1. Long-term reliable source operation with a. 125 W at IF in 2014 b. 250 W in 2015	1. Reliable source operation with > 75% availability – 125 W at IF in 1H / 2015 (at customer)) – 250 W at IF in 1H / 2016 (HVM entry at customer)	1. Reliable source operation with > 85% availability – Expectation of 1500 average wafers per day in 2016
[illegible]ield & defect [illegible] infra[illegible]	2. Mask yield & defect inspection/review infrastructure	2. Resist resolution, sensitivity & LER met simultaneously – Progress insufficient to meet 2015 introduction target	2. Resist resolution, sensitivity & LER met simultaneously – Increased focus needed on manufacturing performance (defectivity, pattern collapse,...)
3. Resist resolution, sensitivity & LER met simultaneously	4. Keeping mask defect free – Availability of pellicle mtg HVM req't – Minimize defect adders during use	[illegible] infrastructure – Enable high yield defect free mas[illegible] blank supply chain	3. Mask yield & defect inspection/review [illegible]structure [illegible] mask tool supply chain rem[illegible]
• EUVL manufacturing integration	4. Resist resolution, sensitivity & LER met simultaneously	3. Keeping mask defect free – Availability of pellicle mtg HVM req't : need integrated industry strategy for solution – Minimize defect adders during use	4. Keeping mask defect free (by EUV pellicle) - Pellicle demonstration in the field (on 3300) required in 2016

Ranked by 14th International EUVL Symposium Program Steering Committee, Maastricht, October 7, 2015

- Defect level of EUV blanks has been greatly reduced over >5years.
- Mask Blank is still considered as a high risk item for EUVL? ...Yes/No

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   - Difficulties in EUV blanks
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3. Summary

HOYA’s strength

- HOYA is the only blanks supplier that covers optical (ArF, KrF), EUV and FPD.
- We have continuing business especially for optical blanks for several decades. We will accelerate EUV blanks development using the infrastructure for 6 inch plates.
- Strong collaboration with stakeholders.

Improved ULE® Glass Substrates for EUVL Masks Blanks

Carlos Duran, Kenneth Hrdina and Junichi Yokoyama
Corning Incorporated

Tsutomu Shoki, Toshihiko Orihara, Shoji Kaneko and Osamu Maruyama
Hoya Corporation

2013 International Symposium on Extreme Ultraviolet Lithography
Toyama, Japan, Oct. 7–10, 2013

Technology relationship

ArF blank technology	EUV blank technology
Defect control of quartz	Defect control of LTEM
	Defect control of Mo/Si multilayer
Defect control of films • Ta binary (ABF) • Cr absorber (TFCx, EBTx)	Defect control of films • Ta alloy absorber and backside film • CrN backside film
Flatness (~200nm, single side)	Flatness (~30nm, both sides)
Methodology tools	Methodology tools
	ABI
DUV control	DUV reflectivity control
	EUV reflectivity control
Matured production engineering. Commitment to HVM.	Automated blank manufacturing line.

Difficulties of EUV blanks development

- Many of the challenges in EUV mask blanks are in defects.

Defect is **simple**: only three sources

- Defect=Defect from (substrate +deposition +environment)

Defect is **difficult**: only three sources but hundreds of root-causes

- Defect=Defect from (substrate +deposition +environment)

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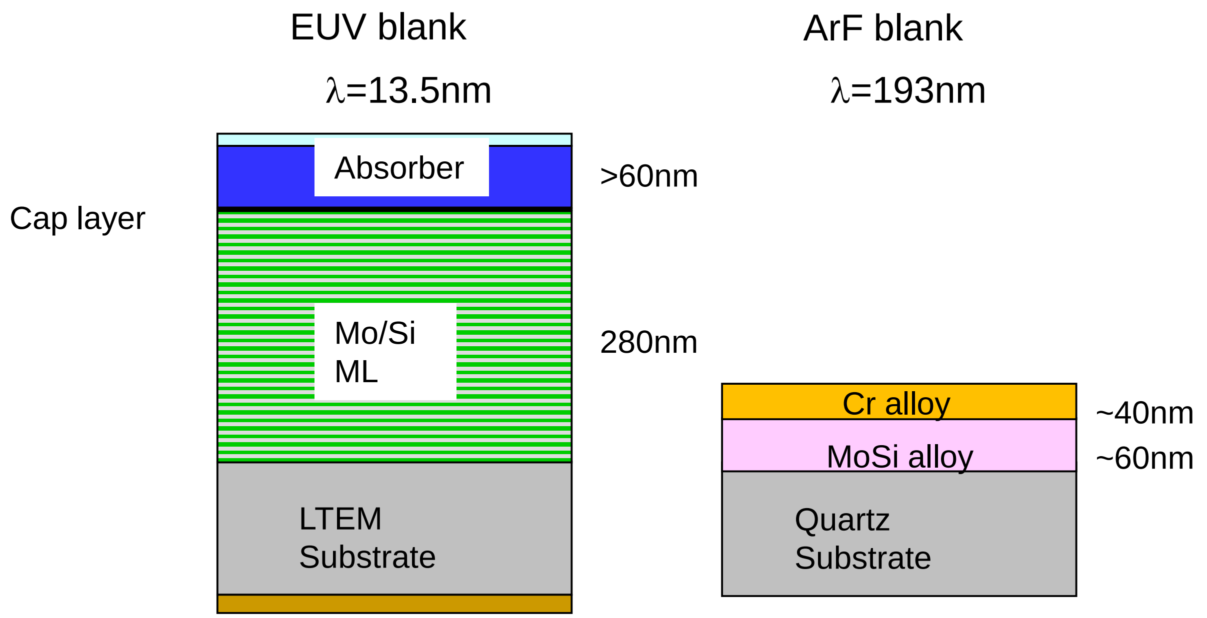
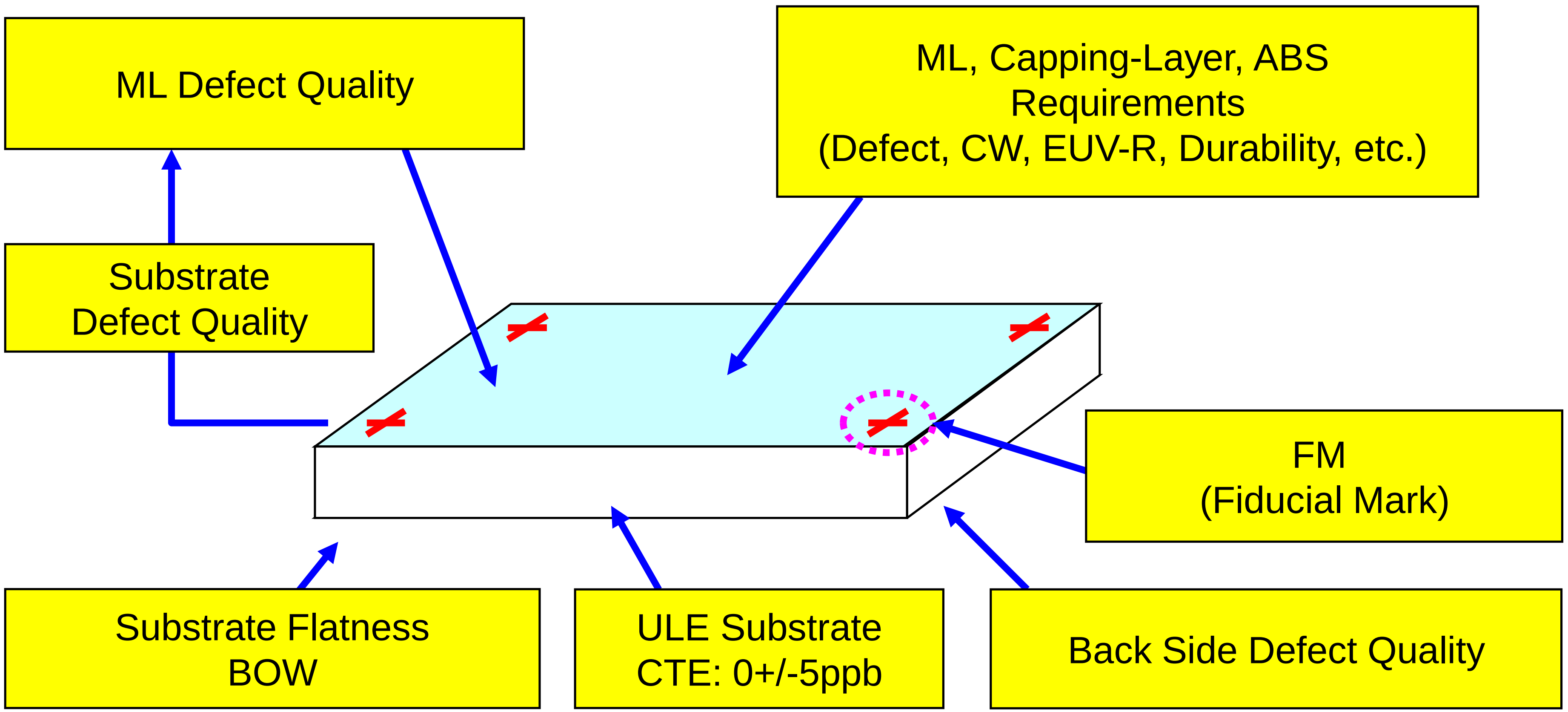
Difficulties of EUV blanks development



- There is no reason that EUV blanks requirement is looser than optical blank.
- Entire thickness of EUV blanks is thick: >3times than optical blank. It means that the chance of particles contamination during film deposition is also >3times. IBD (Ion Beam Deposition) is a unique technology for EUV.
- And do not forget. We have a backside film.
- In total, entire process is long: yield is an issue unless good production engineering & control are maintained.

Difficulties of EUV blanks development

Not only defect..



Defect reduction

Defect identification
- Inspection tool
- ✓ LT Magics
- ✓ Teron
- ✓ ABI
- Location

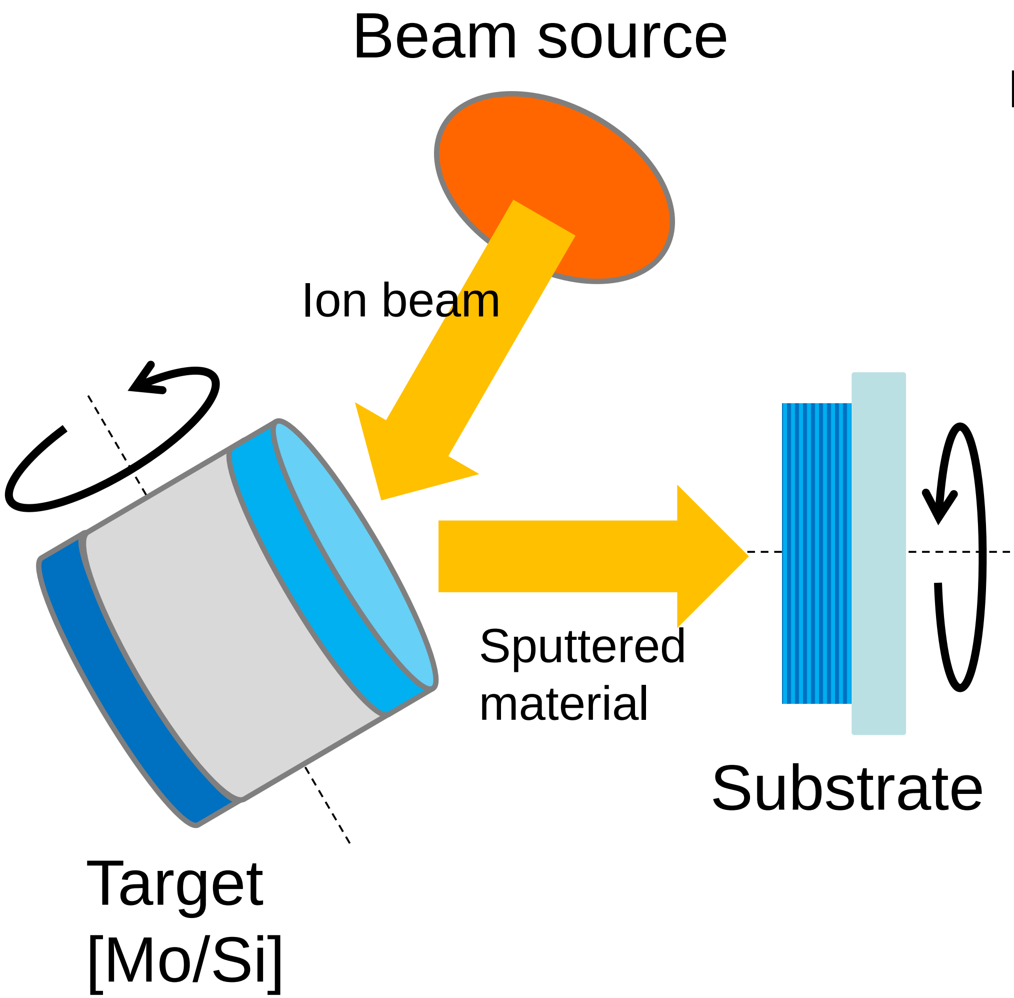
Failure Analysis
- SEM-EDX
- FIB-SEM
- CS-TEM
- AFM
- XPS
- Auger
- …

Root cause verification
- Substrate
- Deposition
- Environment

Preventive action
- Substrate
- Deposition
- Environment

- Failure Analysis is the key.
- Sematech MBDC (Mask Blank Development Center) associate member (2011-2014)

Ion beam sputter deposition

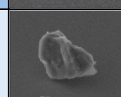
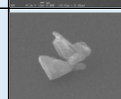
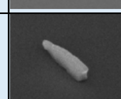
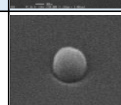
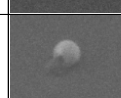


Defect source

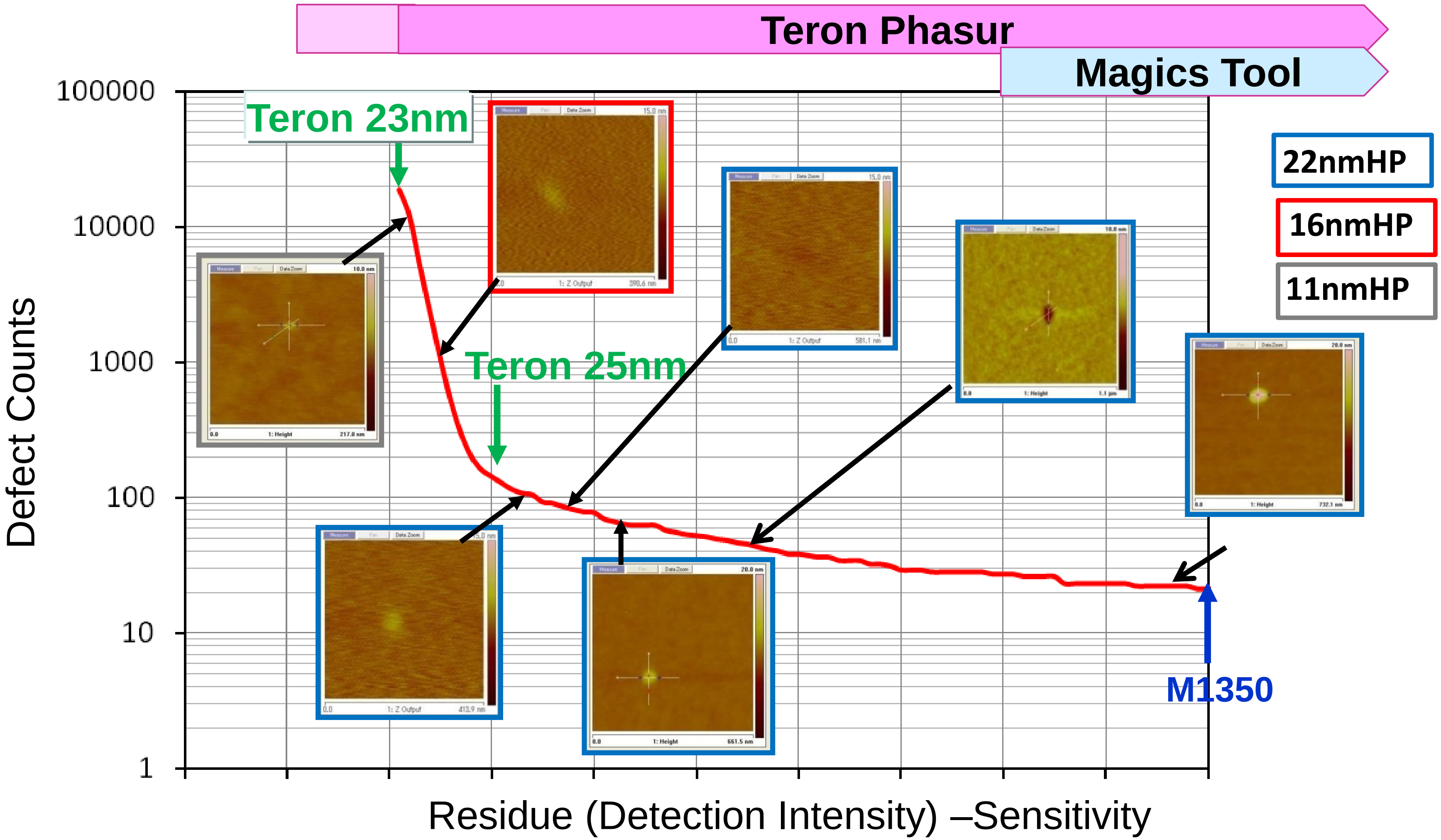
- Remained particles in chamber
- Film peeling from chamber
- Particles on beam grid
- Overspray
- Nodules on target surface
- Particles during transferring
- Mechanical motion
- Chucking

…And many others…

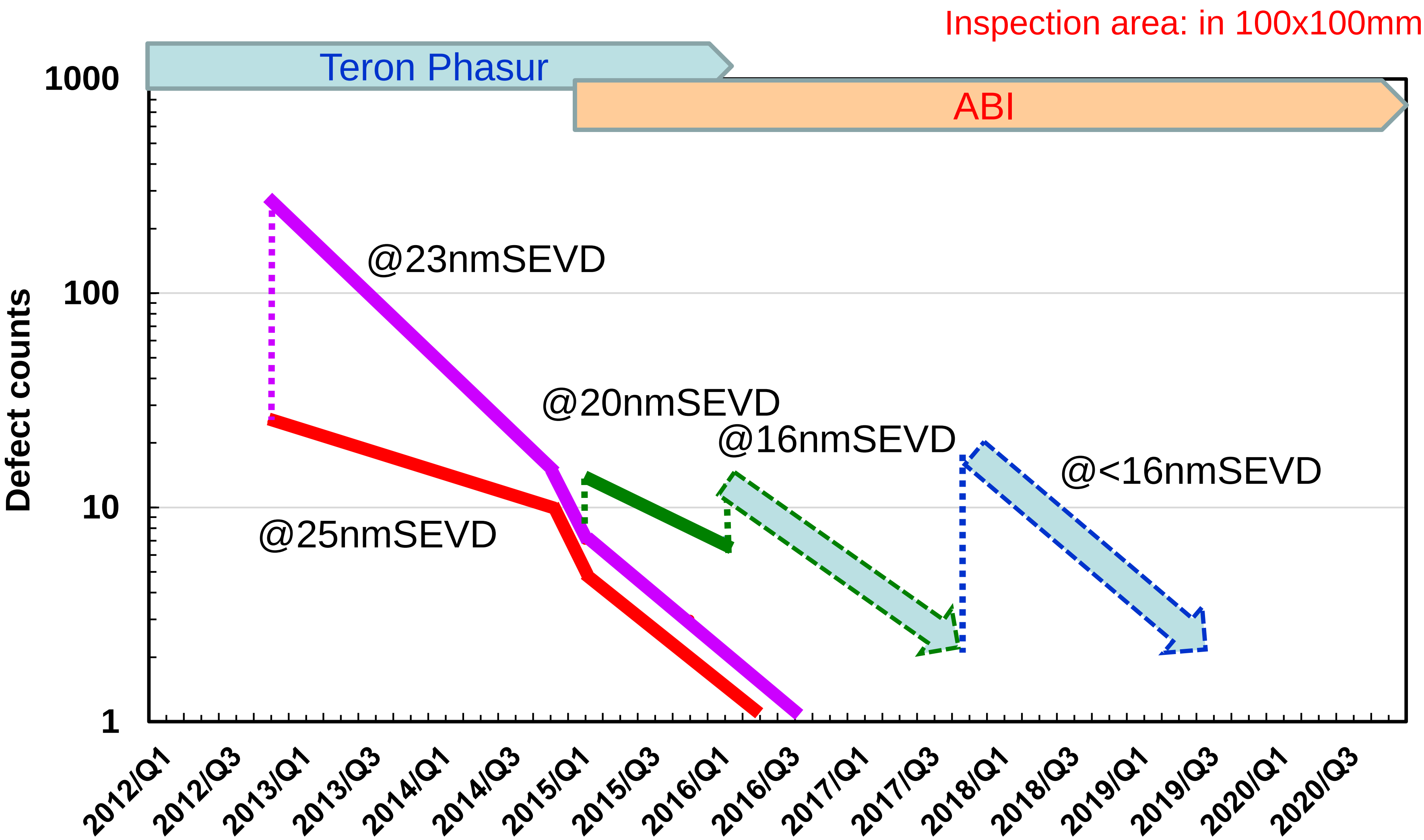
Defect database

Priority	Composition	Ratio	Shape	Factor	Improvement	Schedule						
						2011	2012					
						Dec	Jan	Feb	Mar	Apr	May	Jun
1	A	14%										
	B	10%										
	C	29%										
2	D	5%										
	E	5%										
	F	5%										
3	F	10%										
	G	10%										
	A	10%										

Small size defects



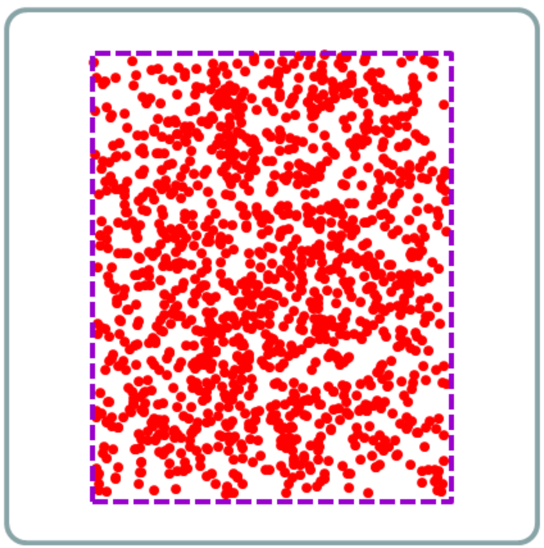
HOYA EUV Blank Defect Reduction (Champion Grade)



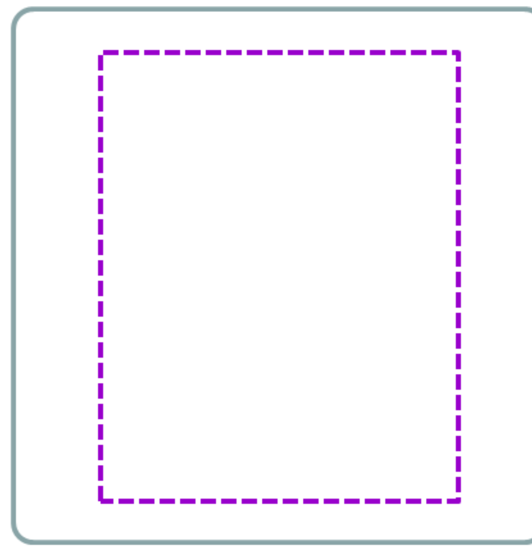
HOYA EUV Blank Defect Reduction history (Teron, Champion Grade)

Area: 132x104mm (max. exposure area)

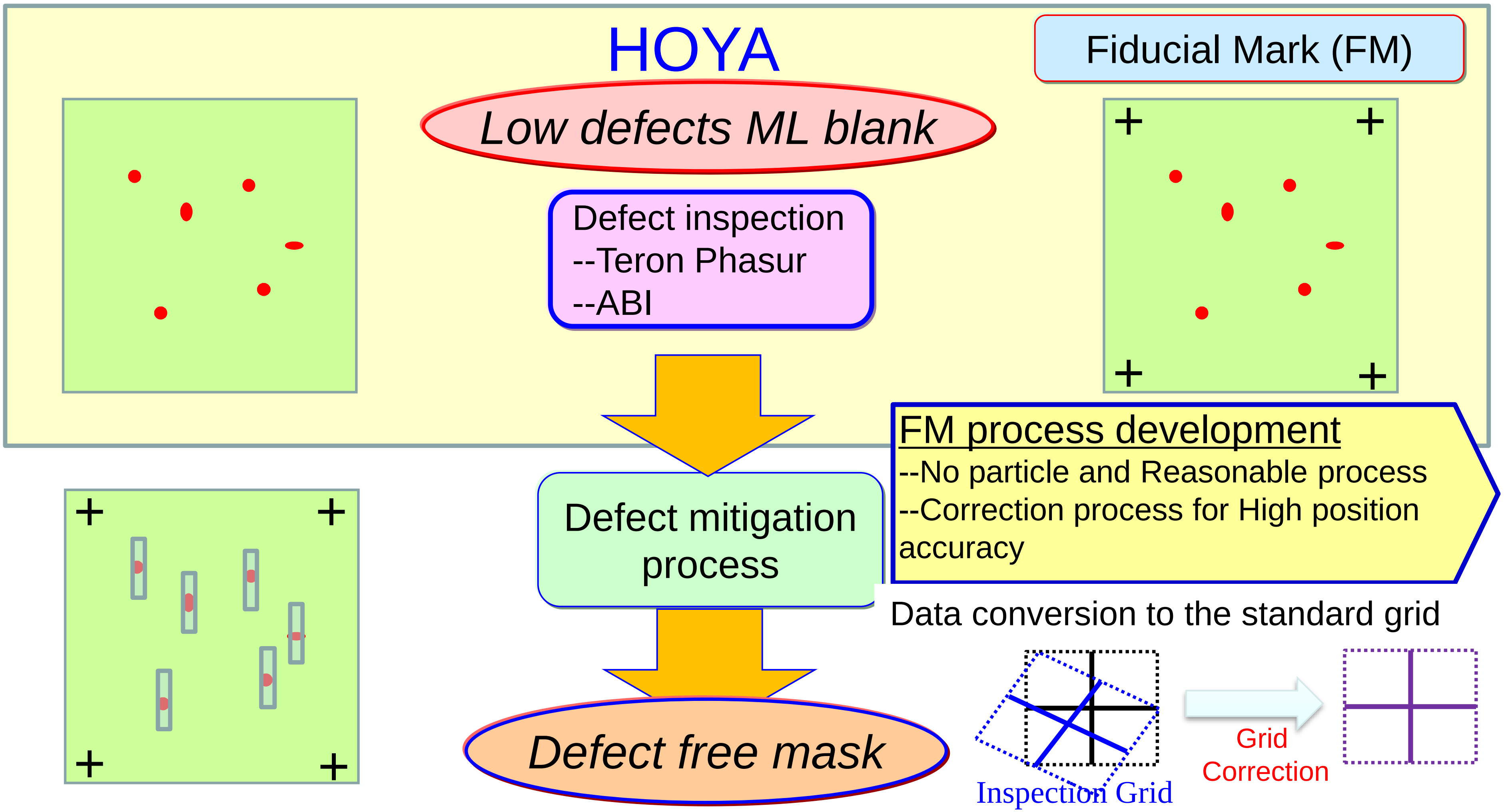
10,000def
@23nm SEVD
in Q1/CY2012



0def
@23nm SEVD
in Q1/CY2016



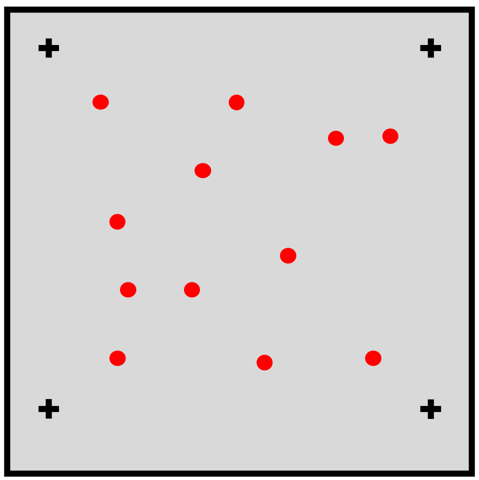
EUV FM Blank Development

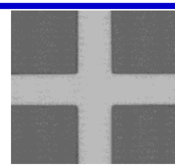


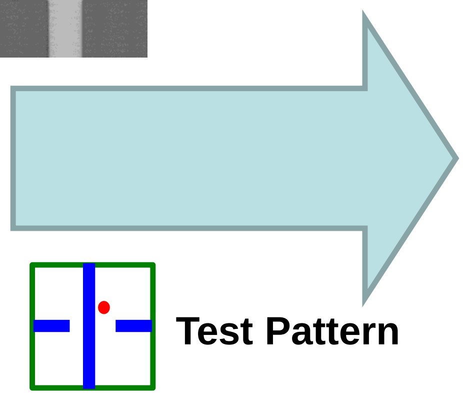
➢ FM blank process is under development for defect mitigation process.

HOYA EUV FM Blank

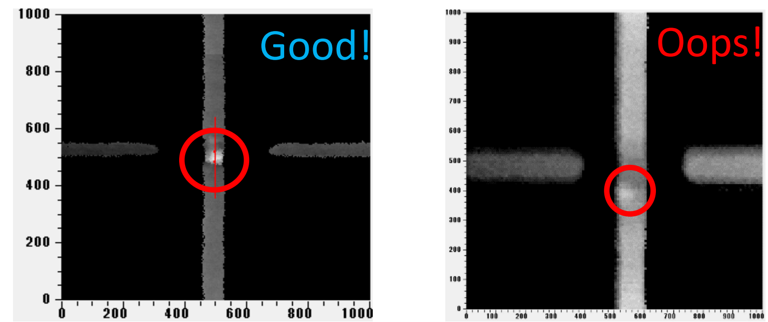
- Fiducial Mark (FM): SEMI-FM
- Defect inspection on Ru-ML
  - Teron (@23nmSEVD) or ABI
- Corrected inspection data on Ru-ML
  - Conversion to the standard grid by original correction
  - Relative defect coordinate to FM (Origin: Blank center)
- All of ML blank defects can be managed to the FM







Defect mitigation test



- HOYA FM blank is workable for defect mitigation process at customers.
- Challenging to further development for achieving higher position accuracy.

Flatness

LETTERS
PUBLISHED ONLINE: 22 NOVEMBER 2009 | DOI: 10.1038/NPHYS1457
nature physics

Breaking the 10 nm barrier in hard-X-ray focusing

Hidekazu Mimura[1]*, Soichiro Handa[1], Takashi Kimura[1], Hirokatsu Yumoto[2], Daisuke Yamakawa[1], Hikaru Yokoyama[1], Satoshi Matsuyama[1], Kouji Inagaki[1], Kazuya Yamamura[3], Yasuhisa Sano[1], Kenji Tamasaku[4], Yoshinori Nishino[4], Makina Yabashi[4], Tetsuya Ishikawa[4] and Kazuto Yamauchi[1,3]

Hard X-rays have exceptional properties that are useful in the chemical, elemental and structure analysis of matter. Although single-nanometre resolutions in various hard-X-ray analytical methods are theoretically possible with a focused hard-X-ray beam, fabrication of the focusing optics remains the main hurdle. Aberrations owing to imperfections in the optical system degrade the quality of the focused beam[1]. Here, we describe an *in situ* wavefront-correction approach to overcome this and demonstrate an X-ray beam focused in one direction to a width of 7 nm at 20 keV. We achieved focal spot improvement of the X-ray nanobeam produced by a laterally graded multilayer mirror[2]. A grazing-incidence deformable

optical components to form an ideal spherical wave. The main obstacle in reaching the ultimate minimum limit is the difficulty in fabricating optical elements of sufficient quality.

On the other hand, various scanning-type microscopes that use electron and ion beams, such as the scanning transmission electron microscope[11] and the atom-probe field-ion microscope[12], already have atomic-level resolution capability. When using these devices, to obtain a nanometre-sized electron or ion beam, the electric and magnetic fields of the electron lenses are finely tuned *in situ*, while simultaneously viewing the sample images. Furthermore, in many kinds of imaging system, from visible microscopes to space telescopes, adaptive optical methods have been implemented to

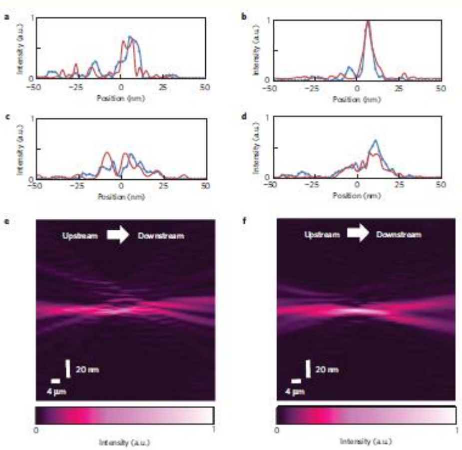


Figure 3 | Comparison between the measured profile and recovered intensity profile of the focused beam in the phase-retrieval calculations. **a,b**, Intensity profiles before (**a**) and after (**b**) wavefront correction on the plane, where the minimum focused beam profile is obtained before wavefront correction. **c,d**, Intensity profiles before (**c**) and after (**d**) wavefront correction, 12 µm downstream from the points corresponding to **a** and **b**. The blue curves in **a**–**d** are the experimentally measured profiles. The red profiles are recovered by phase-retrieval calculations. **e,f**, Predicted beam-waist structure before (**e**) and after (**f**) wavefront correction. The X-ray energy is 20 keV.

HTML ABSTRACT + LINKS

REVIEW OF SCIENTIFIC INSTRUMENTS 76, 063708 (2005)

Fabrication of elliptically figured mirror for focusing hard x rays to size less than 50 nm

Hirokatsu Yumoto,[a] Hidekazu Mimura, Satoshi Matsuyama, and Hideyuki Hara
Department of Precision Science and Technology, Graduate School of Engineering, Osaka University, 2-1 Yamada-oka, Suita, Osaka 565-0871, Japan

Kazuya Yamamura
Research Center for Ultra-Precision Science and Technology, Graduate School of Engineering, Osaka University, 2-1 Yamada-oka, Suita, Osaka 565-0871, Japan

Yasuhisa Sano and Kazumasa Ueno
Department of Precision Science and Technology, Graduate School of Engineering, Osaka University, 2-1 Yamada-oka, Suita, Osaka 565-0871, Japan

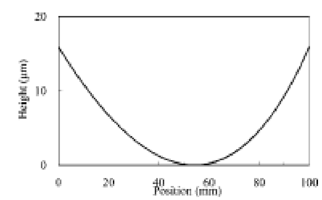


FIG. 2. Designed elliptical profile of the mirror for nanofocusing of hard x ray.

cusing conditions. The FWHM and the width between the first two minima are 36 and 68 nm, respectively. The latter width is almost the same as that easily predicted using Eq. (2).

III. FABRICATION OF HARD X-RAY FOCUSING MIRROR

The x-ray mirror was fabricated by figuring a Si (111) substrate surface shape into a designated one with required accuracy for nanofocusing, using computer-controlled EEM and PCVM and then by coating platinum on the figured surface area, using a scanning-type platinum deposition system.[7]

In our fabrication system, metrology plays an important role because computer-controlled figuring is carried out on

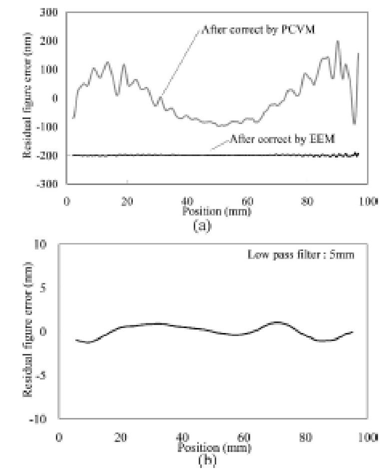
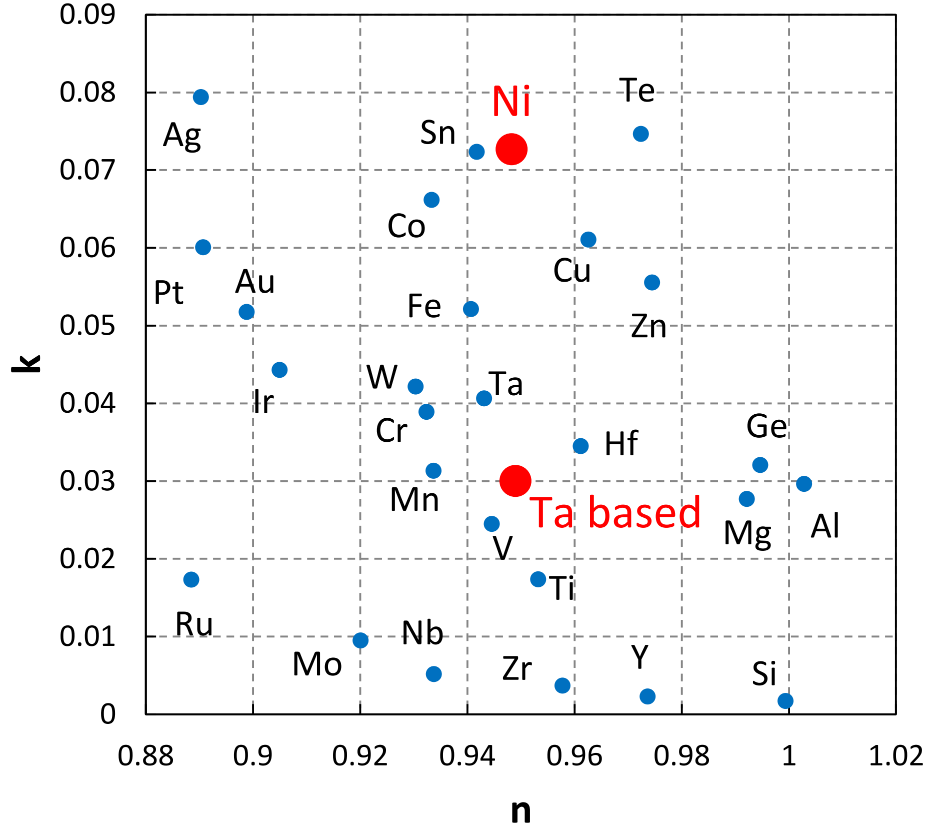
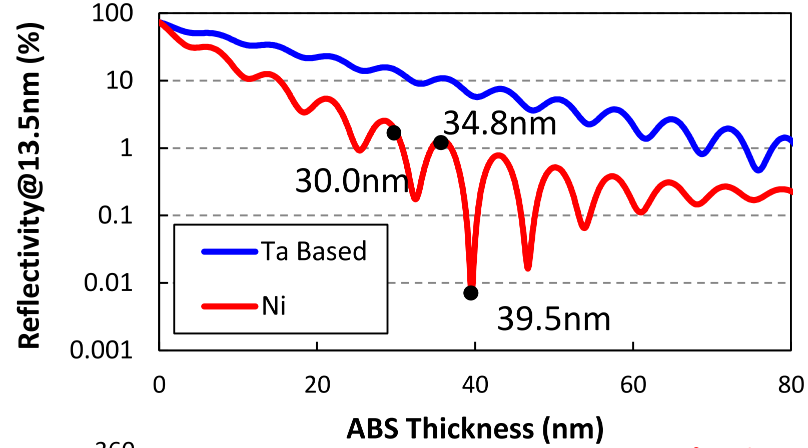


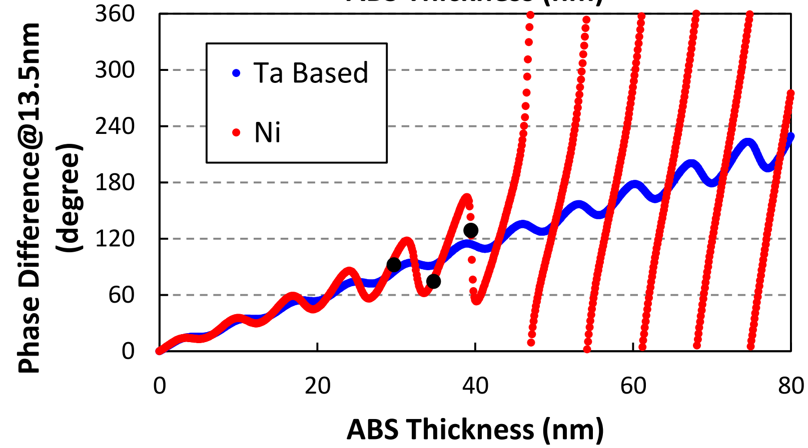
FIG. 4. Residual figure error profiles of the fabricated mirror after PCVM figuring and EEM figuring 5 mm low pass filtered profile (b) shows that the figure error at relatively long spatial wavelength ranges is removed at the required degree of figure accuracy.

- There are techniques to achieve flatness <10nm, but at a cost of process time and probably defects.
- For EUV-HVM application, “viable” solution is needed.

Absorber development







Reflectivity 2% over 30nm Ni thickness.

Minimum reflectivity can be obtained at 39.5nmt.

Ref. Development of thin absorber for EUV blanksYohei Ikebe, Tsutomu Shoki, Takahiro Onoue Presented at EUVL symposium 2016 on 24Oct.

Backside Film Development

High CoF (Coefficient of Friction)

CrN Back side film (Standard)

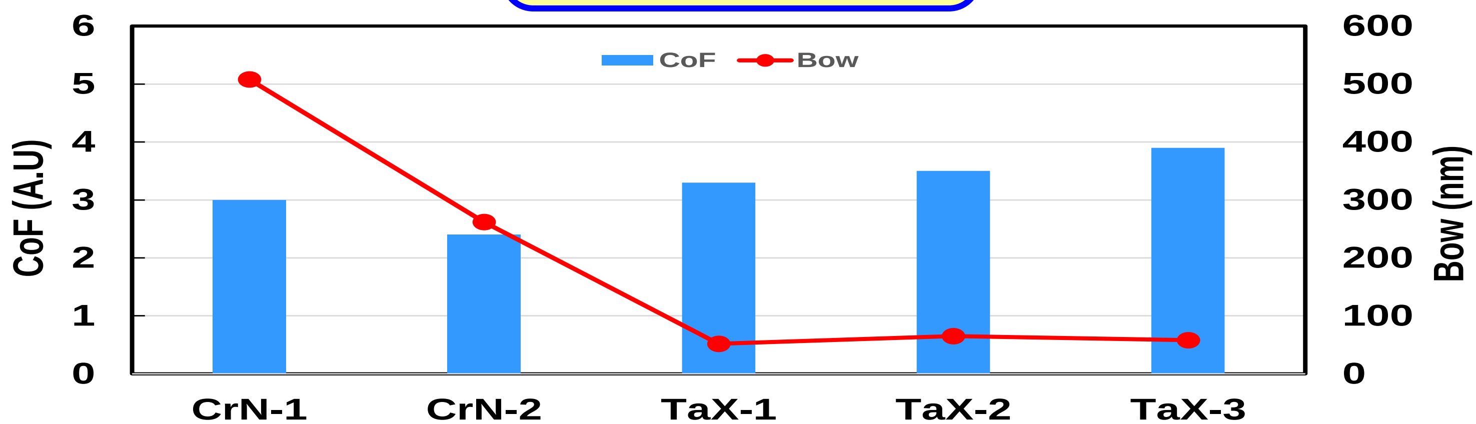
Small Bow (Blank flatness)

- ✓ Higher CoF is needed to more firmly hold the reticle at high accelerations
- ✓ High adhesion and high wear durability are useful for stable and damageless e-chucking.

- ✓ Smaller bow of <300nm is required for meeting the NXE overlay requirement for 16nmhp.

Ta based films

- ✓ Good cleaning durability
- ✓ Good stress controllability



- ➢ **HOYA developed TaX-3 (TaB) backside film for higher CoF and smaller bow.**
  - ➢ **Very small bow can be produced by application of Ta based back side film.**

HOYA TaB Backside Film

	Requirement	CrN (Standard)	TaB (New)
Sheet Resistance	<100 Ohm/sq.	Pass	Pass
Surface roughness	≦0.6nm Rms	Pass	Pass
Scratch test* [Critical load mN]	Better than CrN	Pass	Pass (2x better)
Wear rate* $X10^{-7}$ mm^3/Nmm	Better than CrN	Pass	Pass (5x better)
CoF*	>0.3	Pass	>0.3
Bow	300nm	500nm	Pass (3x better)

*Measured by ASML under their definition

- TaB film passed all of the requirement for e-chucking process.
- TaB showed better performance in scratch and wear test than CrN.

Summary

Defect performance:

- Defect performance has significantly improved over the past 6 years.
  - Steady defect analysis work and aggressive trials for defect improvement
  - Integration with HOYA production technologies
  - Collaboration with key stakeholders
- Correlation with defect printability.

EUV blanks for HVM:

- Aggressive proposals such as TaB backside film
- Total performance including factors other than defects
- Maturity is required. It will be brushed up through actual exposure.

EUV blanks for the next:

- Beside defects. Acceleration of development, for example absorbers.
- Support from stakeholders for investment toward HVM.

Mask Blank is ~~considered as~~ a ~~high risk~~ key item for EUV Lithography.

A first step toward maturity.

Acknowledgement

- Hoya team
- Great appreciation to ASML team for evaluation of TaB backside film.