2014 EUVL Workshop

Progress of Optical Design for EUV Lithography Tools in BIT

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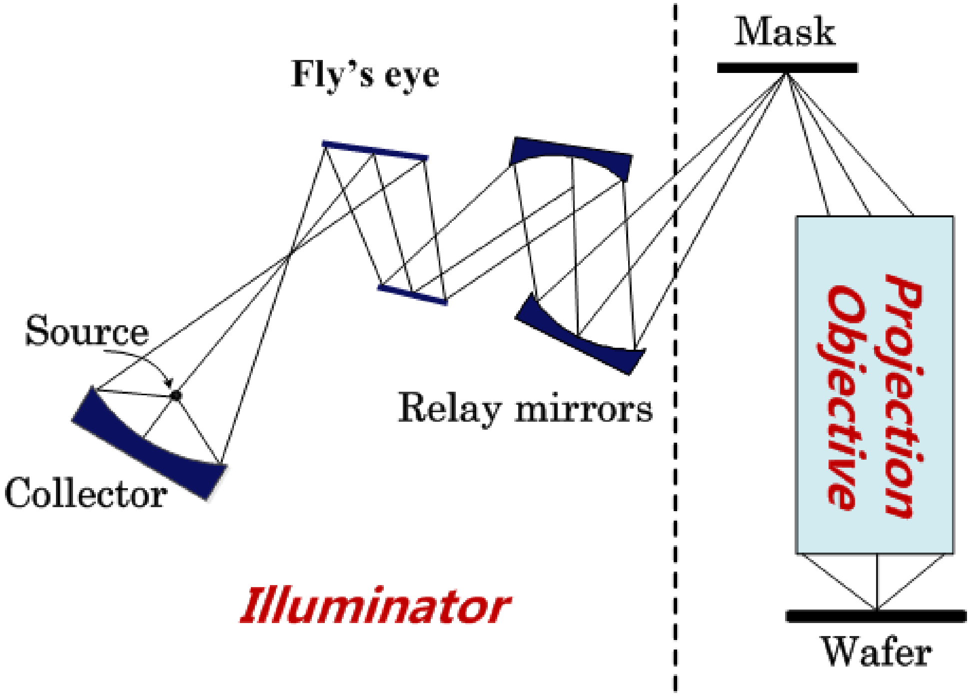
OUTLINE

- **Introduction**
- **Design of EUV projection objective**
  - *Grouping design method*
  - *Design of co-axial objective systems*
  - *Design of off-axial objective systems*
- **Design of EUV illuminator**
  - *Reverse design/adjustment method*
  - *Design results*
- **Acknowledgment**

Introduction



Constraints for Objective

- *High resolution*
- *Almost none distortion*
- *Telecentricity on image side*
- *Accessible Stop*
- *Working distance*
- *Low aspheric departure*
- *Small angle of incidence*
- *Chief ray angle at mask*
- *Total Tack*

… …

Constraints for illuminator

- *pupil matching*
- *high uniformity at the arc-shaped field*

Introduction

Trend of NA for projection objective

ADT & NXE 3100

NEX 3300

11nm node

8nm node

HP	45nm	32nm	22nm	16nm	11nm
NA0.25	0.83	0.59	0.41	0.30	
NA0.30		0.71	0.49	0.36	
NA0.33		0.78	0.54	0.39	
NA0.35		0.83	0.57	0.41	0.29
NA0.40			0.65	0.47	0.33
NA0.45			0.73	0.53	0.37
NA0.50			0.81	0.59	0.41
NA0.60				0.71	0.49
NA0.70				0.83	0.57

$$RES\downarrow = \frac{k_1 \cdot \lambda}{NA\uparrow}$$

**** New design forms are needed !***

**** New design strategy is required !***

Introduction

What is new in this year's presentation ?

I Design of co-axial objective systems

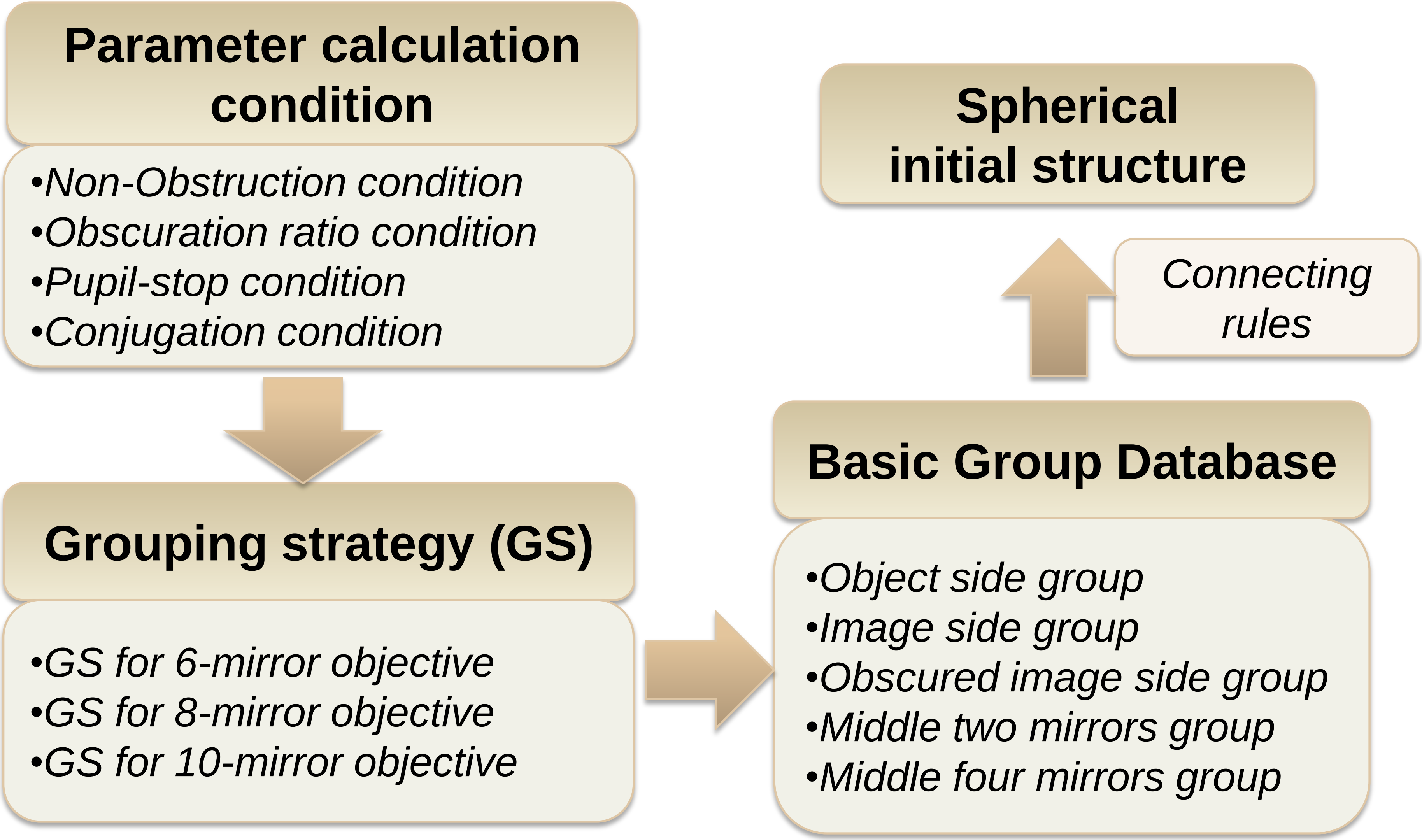
1. 6M objective with central obscuration (NA0.5)
2. 8M unobscured objective (NA0.4)
3. 10M objective with central obscuration (NA0.75)

II Design of off-axial objective systems

6M unobscured objective (NA0.4)

III Design of EUV illuminator

Grouping Design for EUVL Objective



Parameter calculation condition

- *Non-Obstruction condition*
- *Obscuration ratio condition*
- *Pupil-stop condition*
- *Conjugation condition*

Grouping strategy (GS)

- *GS for 6-mirror objective*
- *GS for 8-mirror objective*
- *GS for 10-mirror objective*

Basic Group Database

- *Object side group*
- *Image side group*
- *Obscured image side group*
- *Middle two mirrors group*
- *Middle four mirrors group*

Connecting rules

Spherical initial structure

Basic Mirror Groups

Five Kinds of Mirror Groups

Object side group (G1)

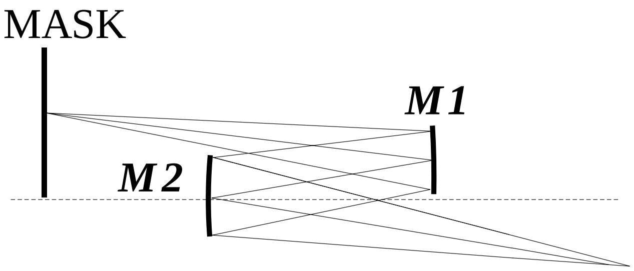
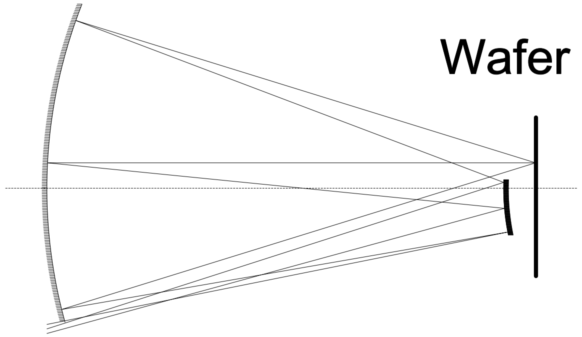
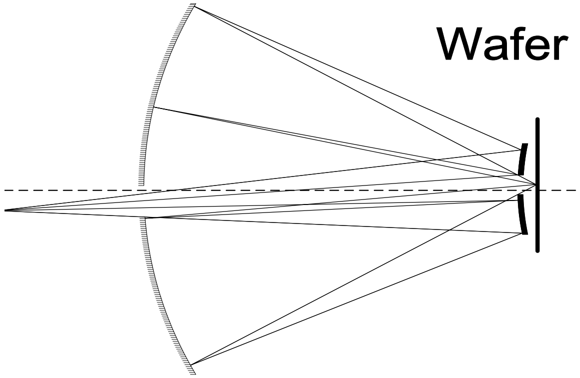


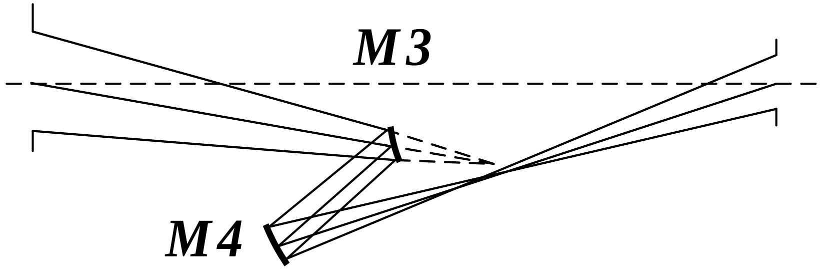
Image side group (G3)



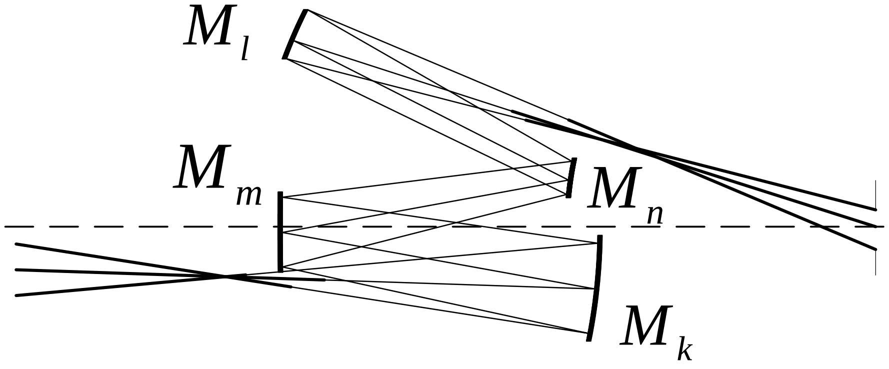
Obsc-image group (G3’)



Middle two-mirror group (G2)



Middle four-mirror group (G2’)



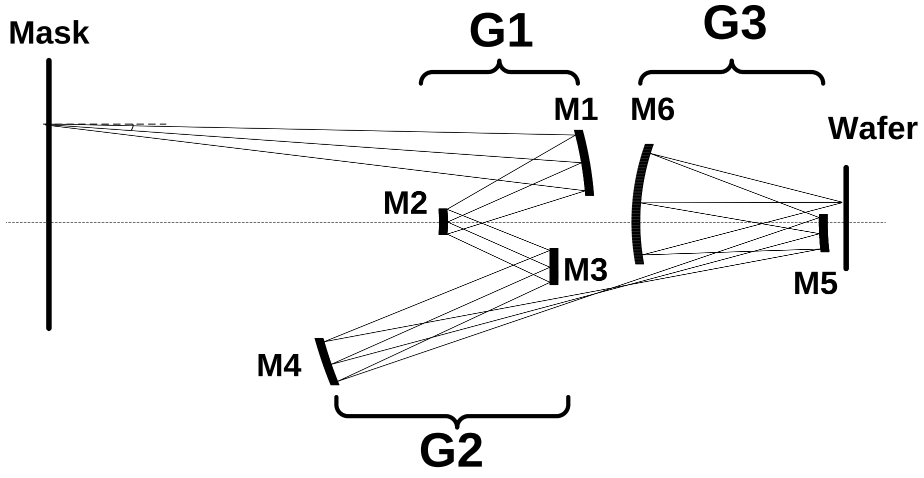
Basic mirror groups

Connect

All-sphere initial structure

Grouping Strategy

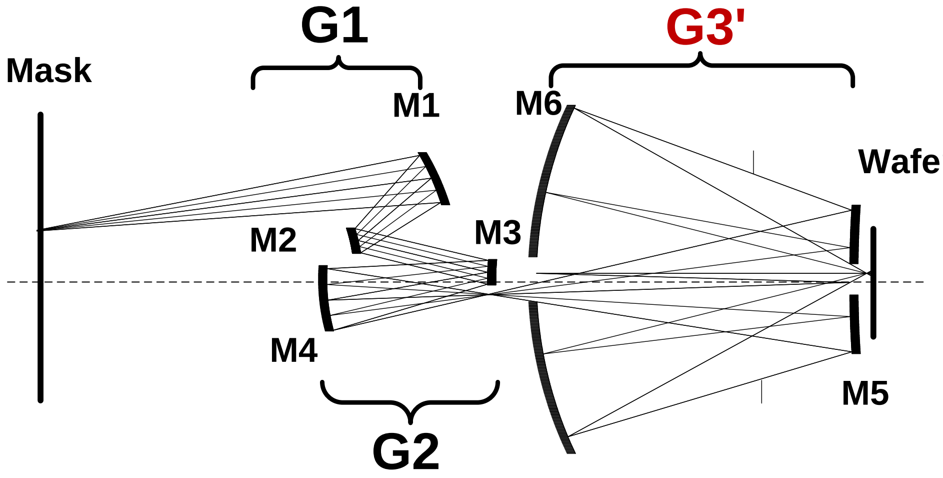
6M unobscured objective :



G1: *M1, M2*
G2: *M3, M4*
G3: *M5, M6*

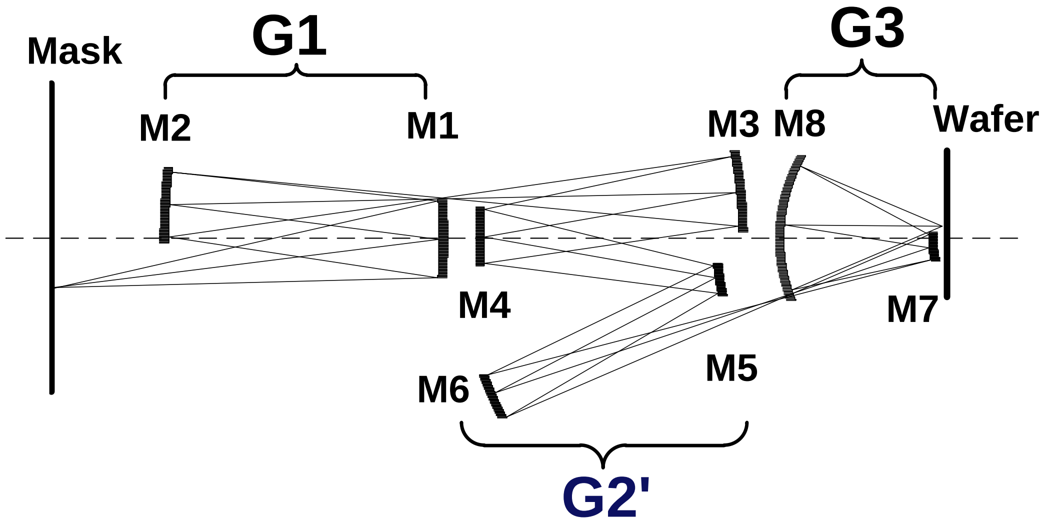
6M objective with central obscuration :

G1 : *M1, M2*
G2 : *M3, M4*
G3': *M5, M6*



Grouping Strategy

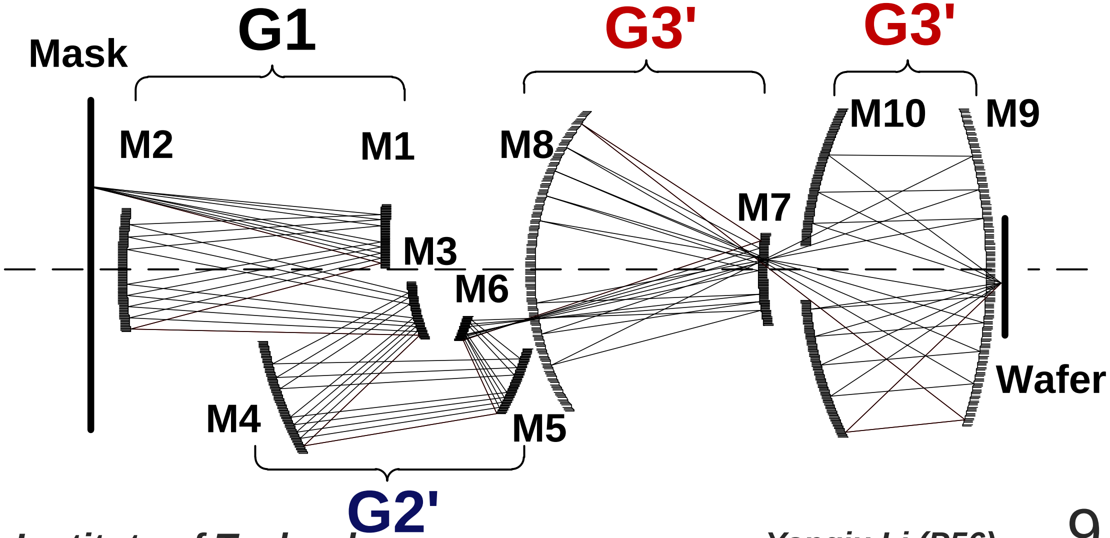
8M unobscured objective



G1 : *M1, M2*
G2’ : *M3, M4, M5, M6*
G3 : *M7, M8*

10M objective with central obscuration

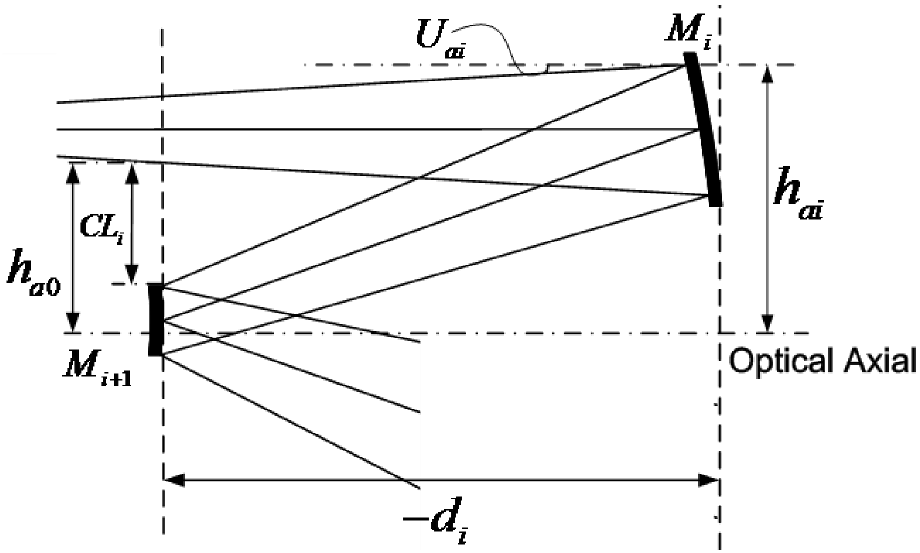
G1 : *M1, M2*
G2’ : *M3, M4, M5, M6*
G3’ : *M7, M8*
G3’ : *M9, M10*



Parameter Calculation Condition

Non-obstruction condition: *The radius of one mirror can be expressed as a function of the clearance.*

Clearance: The distance between the edge of a mirror and the beam near it.

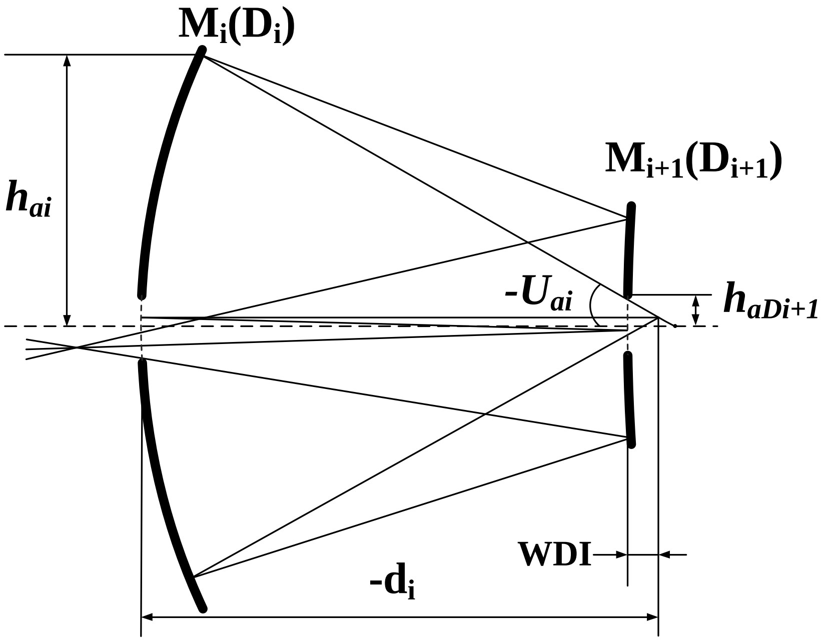


U_{ai}	*the slope angle of the upper marginal ray on* M_i
h_{ai}	*the ray height of the upper marginal ray on* M_i
h_{a0}	*the ray height of the ray beam near* M_{i+1}

$$c_i = \sin\left(\frac{U_{ai}}{2} - \frac{\arctan\left(\left(h_{ai} - \left(h_{a0} - CL_i\right)\right) / \left(-d_i\right)\right)}{2}\right) \Big/ h_{ai} .$$

Parameter Calculation Condition

Obscuration Ratio condition: *The radius of one mirror can be expressed as a function of the ratio of hole to whole mirror diameter.*

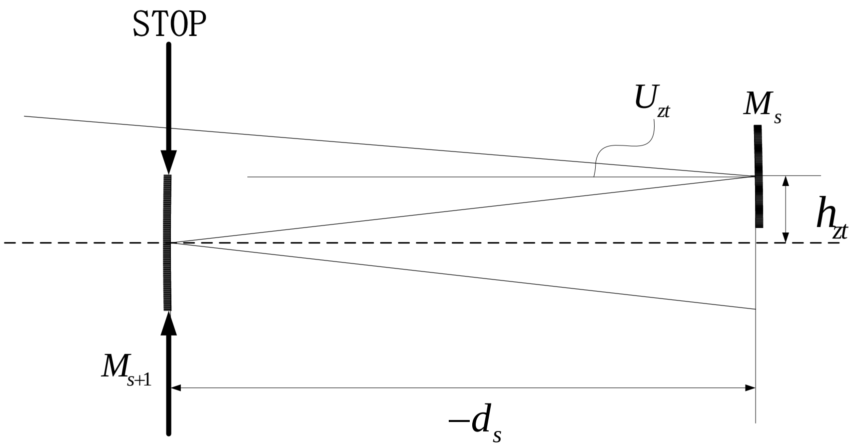


U_{ai}	*the slope angle of upper marginal ray of* M_i
h_{ai}	*height of upper marginal ray of* M_i
h_{aDi}	*height of upper marginal ray of the virtual surface* D_i
$radio_i$	*the diameter ratio of the hole to the mirror* M_i

$$c_i = \sin\left\{\frac{U_{ai}}{2} - \frac{\arctan\left[(h_{aDi+1}/radio_{i+1} - 2h_{aDi+1} + h_{ai})/(-d_i)\right]}{2}\right\} \Bigg/ h_{ai}$$

Parameter Calculation Condition

Pupil-stop condition: *Surface parameter is the function of the pupil or stop position .*



h_{zs} *chief ray height on* M_s

$-d_s$ *separation between* M_s *and* M_{s+1}

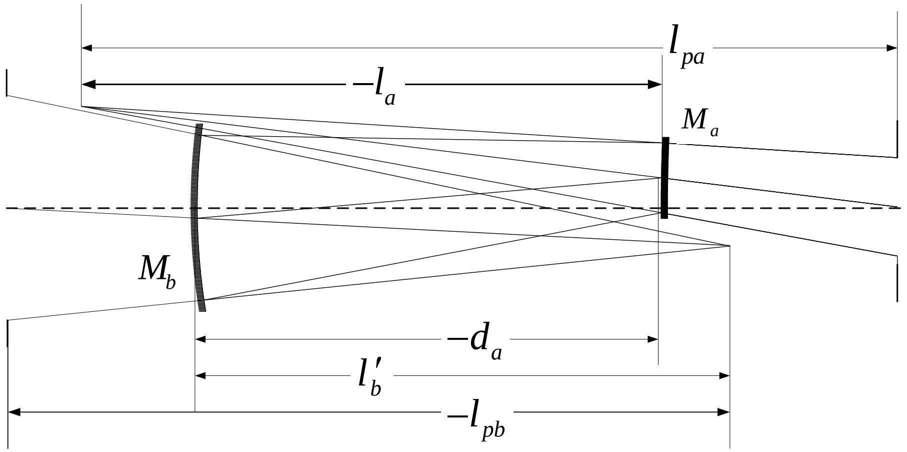
U_{zt} *slope angle of the chief ray on* M_s

z_{zs} *the along optical axial distance of the incident point on* M_s

$$c_s = \sin\left(\frac{\arctan\left(h_{zs}/(-d_s+z_{zs})\right)}{2}-\frac{U_{zt}}{2}\right)\Big/ h_{zs} .$$

Parameter Calculation Condition

Conjugation condition: *Surface parameters should match the adjacent groups' properties (e.g. petzval sum, object-image, Magification, pupil matching).*



$$\begin{cases} d_{a-1} = l'_{a-1} - l_a = l'_{a-1} + Ml_{pa}l'_{pb}\left(-ps \cdot A \pm \sqrt{ps^2A^2 - 4AB}\right)\Big/A \\ c_a = -\frac{1}{2}\left(ps \pm \sqrt{ps^2 - 4B/A}\right) \\ d_a == A\Big/\left(Ml'_{pb}l_{pa}\left(M^2l_{pa} + 2Ml'_{pb}psl_{pa} - l'_{pb}\right)\right) \\ c_b = ps + c_a \\ d_b = l_b{}' - l_{b+1} = TT + l_a - d_a - l_{b+1} \end{cases}$$

M *denotes the magnification of the middle two mirror group*

$$ps^2A^2 - 4AB > 0$$

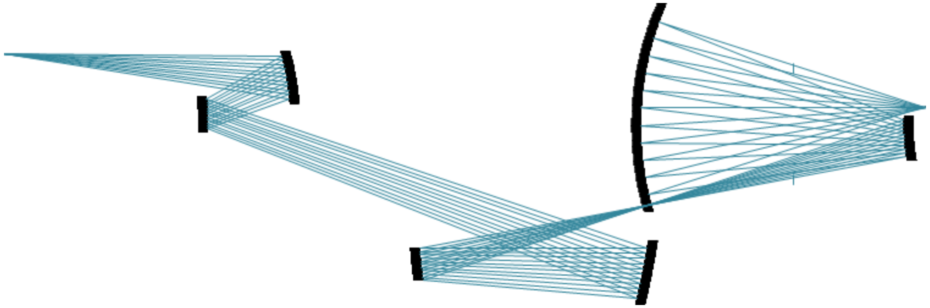
$$\begin{cases} A = Ml'_{pb}l_{pa}\left(l_{pa}M^2TT + M^2l'_{pb}l_{pa} + 2Ml'_{pb}l_{pa} - l'_{pb}l_{pa} + l'_{pb}TT\right) \\ B = -ps^2M^2l_{pa}{}^2l'_{pb}{}^2 - \frac{1}{2}M^2l'_{pb}l_{pa} + \frac{1}{4}M^4l_{pa}{}^2 + \frac{1}{4}l'_{pb}{}^2 \end{cases}$$

ps *denotes the pezval sum of it*

Design of co-axial objective systems

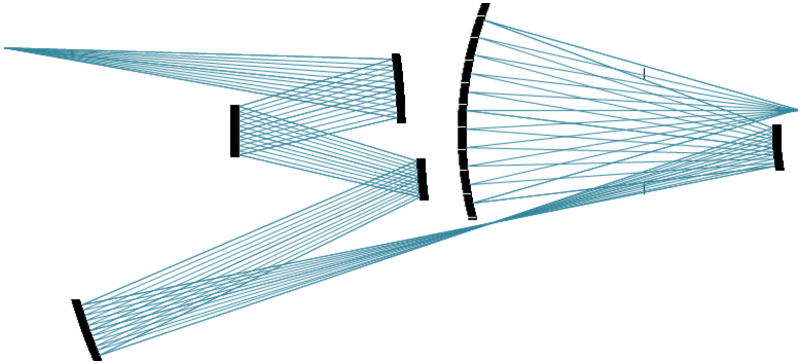
6M unobscured objective

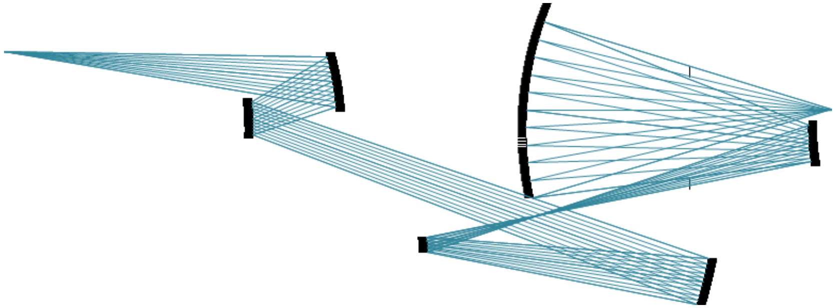
—presented in 2013 EUVL work shop



NA	**0.3**
MAGNIFICATION	1/4
TOTAL TRACK	1530mm

NA	**0.3**
MAGNIFICATION	1/4
TOTAL TRACK	1239mm



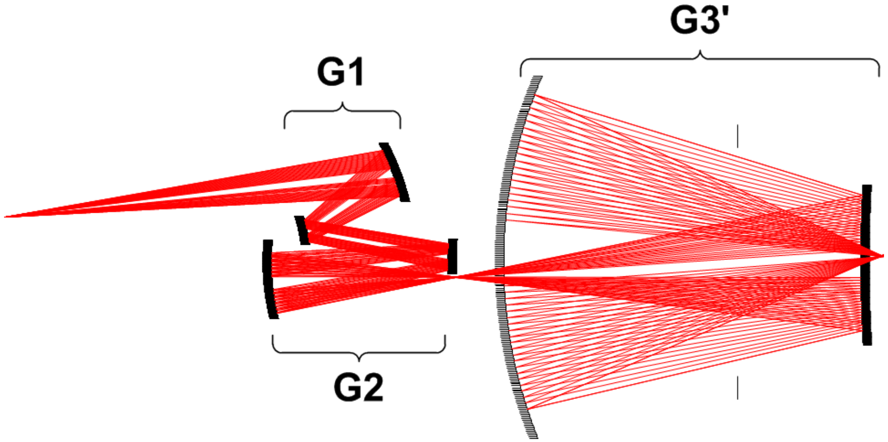


NA	**0.3**
MAGNIFICATION	1/4
TOTAL TRACK	1280mm

Design of co-axial objective systems

1. 6M objective with central obscuration

*To enable **11nm node**, 6-mirror with central obscuration is one of the solutions. The NA of the objective is around 0.45.*

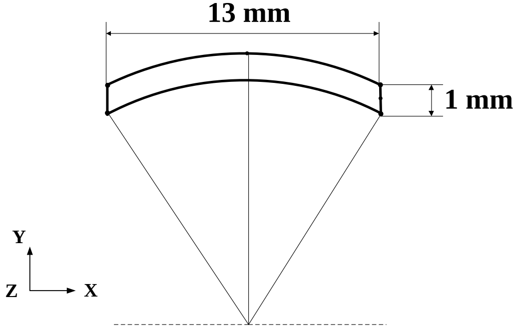


Our latest design form

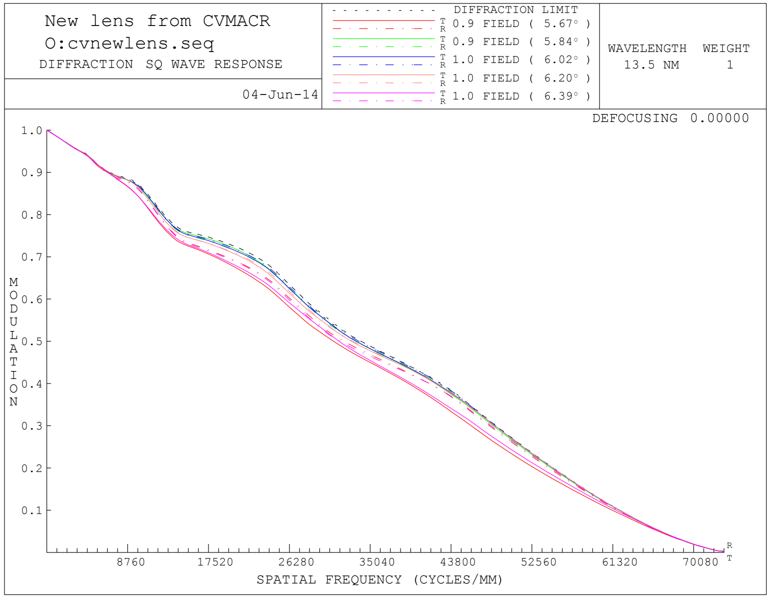
- ***G3'** is calculated under obscuration ratio condition firstly.*
- ***G2** is then calculated under non-obstruction condition.*
- *To match the ray path of **G2** and **G3'**, **G1** can be determined under conjugation condition.*

Design of co-axial objective systems

Performance



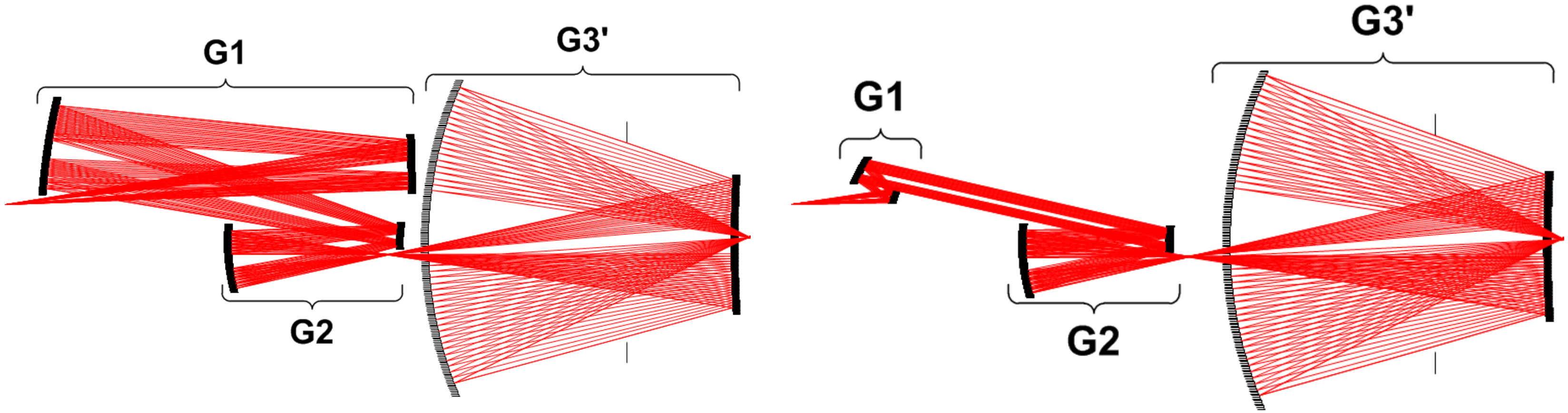
Ring field



Wavelength	**13.5nm**
Numerical aperture	**0.5**
A field of view	**13mm×1mm**
Reduction	**8**
Total track	**1630mm**
working distance	**34mm**
Chief ray angle on mask	**<6.0°**
Chief ray angle on wafer	**0.01°**
Wavefront error (RMS)	**0.0285λ**
Distortion	**<1.2nm**
Pupil obscuration	**<25%**

Design of co-axial objective systems

Generation of new design forms



Other design forms

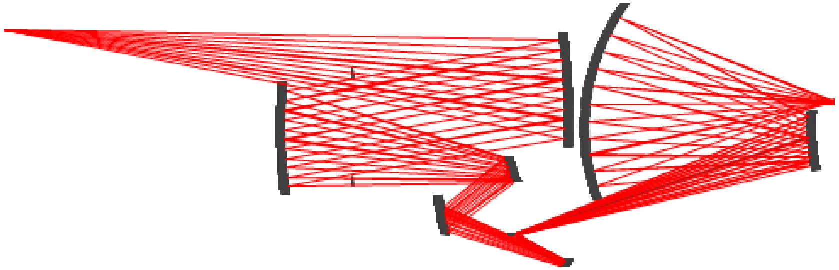
- **G3’** *is fixed. Changing the separations of mirrors in* **G2**, *new design forms of* **G2** *will be obtained.*

•*To connect* **G2** *and* **G3**, *the design forms of* **G1** *will be changed accordingly.*

•*A new initial design are obtained by connecting the three groups.*

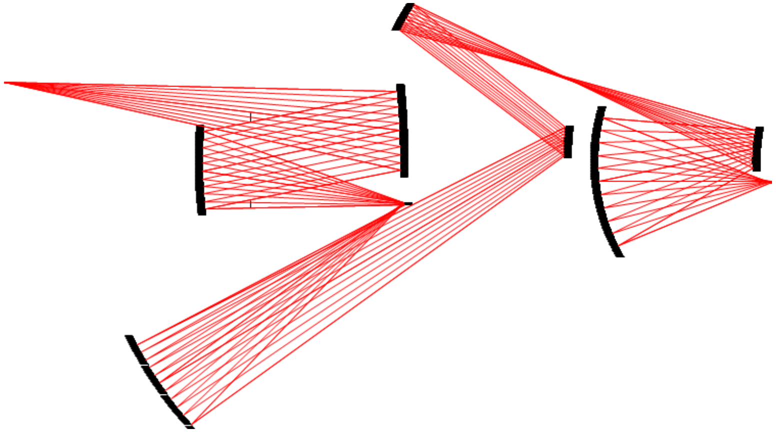
Design of co-axial objective systems

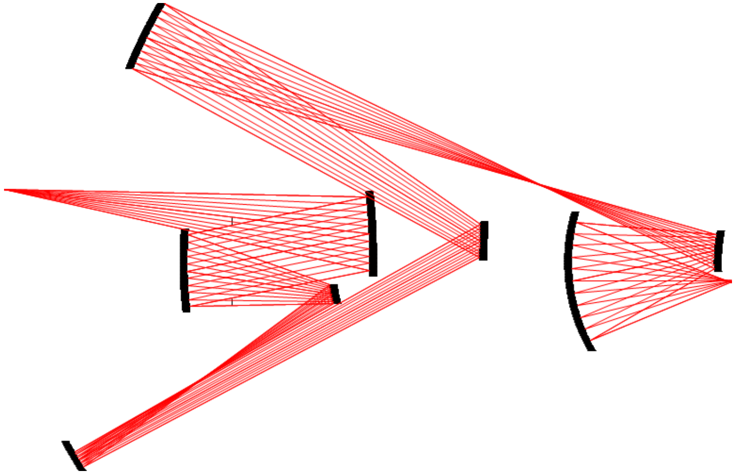
2. 8M unobscured objective



NA	**0.4**
Reduction	4
TOTAL TRACK	947mm

NA	**0.4**
Reduction	4
TOTAL TRACK	1235mm

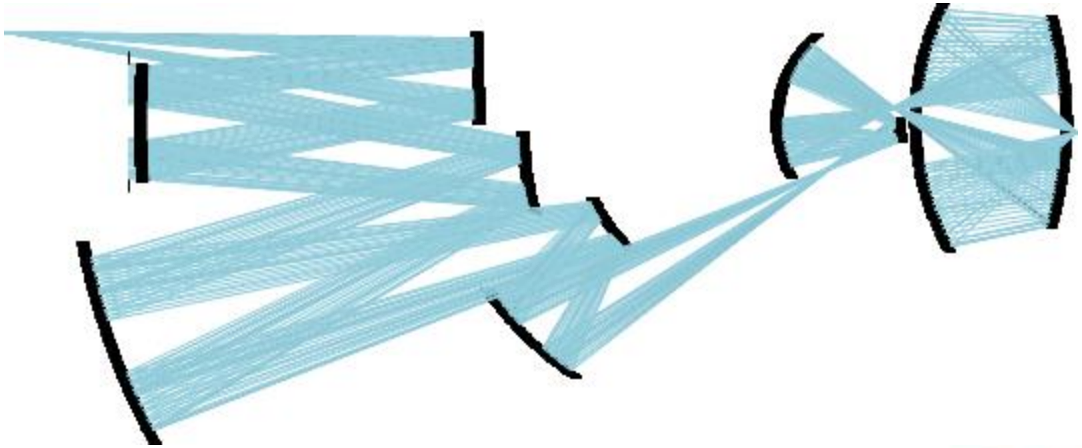




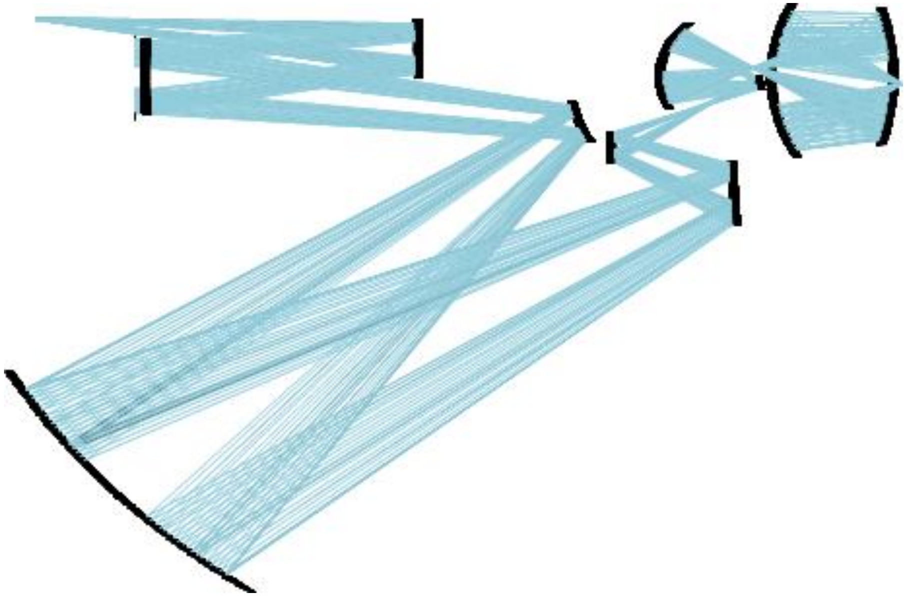
NA	**0.4**
Reduction	4
TOTAL TRACK	1274mm

Design of co-axial objective systems

3. 10M Objective with central obscuration



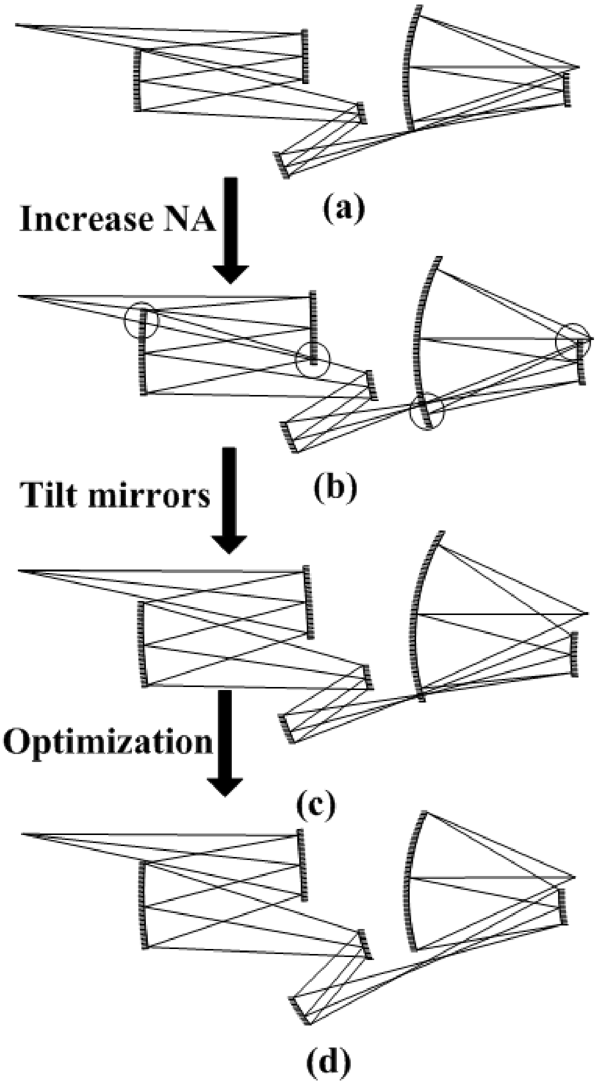
NA	0.7
Reduction	8
TOTAL TRACK	2743mm



NA	0.7
Reduction	8
TOTAL TRACK	2743mm

Design of off-axial objective systems

1. 6M objective off-axial unobscured system



→ Coaxial objective with NA 0.3

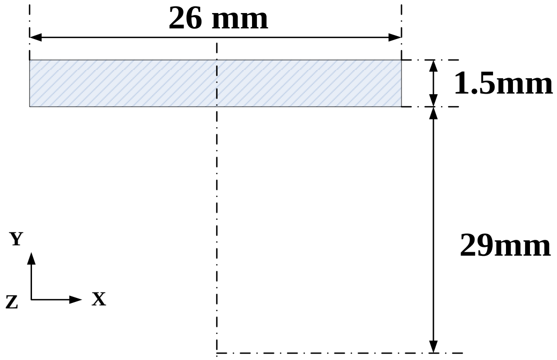
→ NA is increased to 0.4 and obscuration occurs

→ NA 0.4 off-axial objective without obscuration

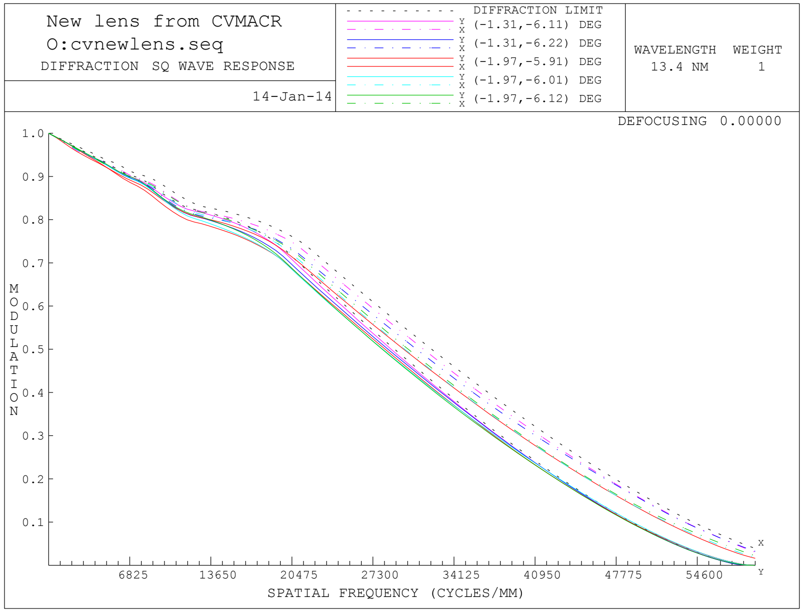
→ Optimized objective with XY-polynomial surface

Design of off-axial objective systems

Performance



Rectangular field

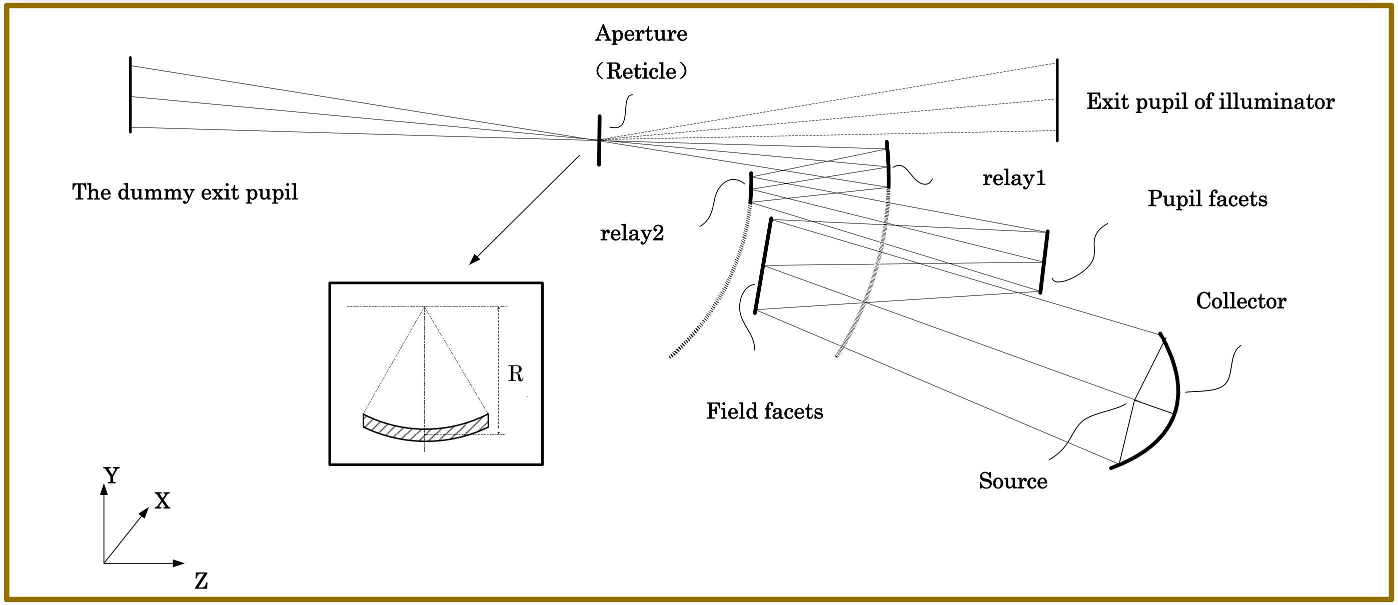


Wavelength	**13.5nm**
Numerical aperture	**0.4**
A field of view	**26mm×1.5mm**
Reduction	**4**
Total track	**1263mm**
working distance	**35mm**
Chief ray angle on mask	**<6.0°**
Chief ray angle on wafer	**0.18°**
Wavefront error (RMS)	**0.034λ**
Distortion	**1.8nm**

Reverse design/ adjusting method for illuminator

Reverse design method:

- Object of the illuminator----exit pupil of objective
- Stop of the illuminator-----arc shape field
- Design target: to match IF of given plasma source
- Para-position for pupil facets and field facets to ensure the illumination uniformity



Reverse design/ adjusting method for illuminator

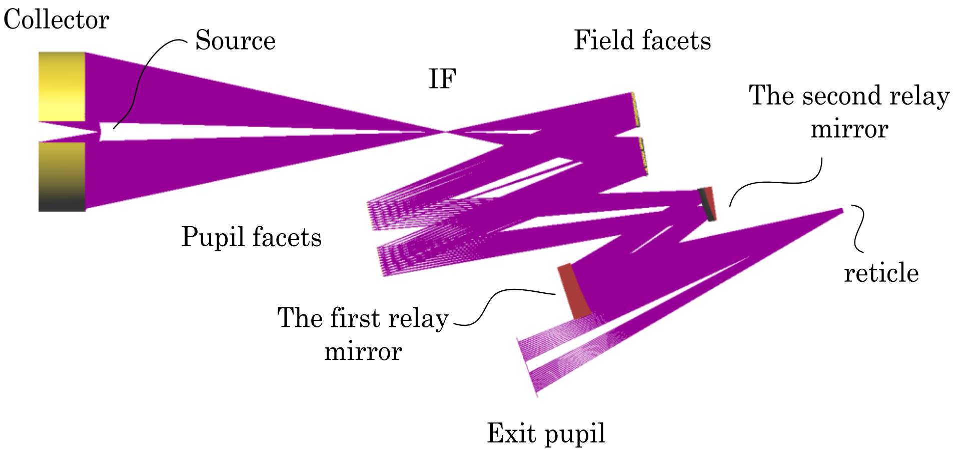
Reverse adjusting method:

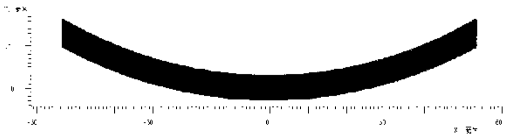
- A adjusting method for illuminator to match objectives with different NA and pupil parameters.

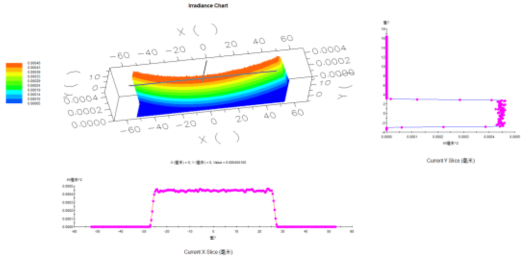
- Only the position of the component is adjusted. The figure of the component is the same.

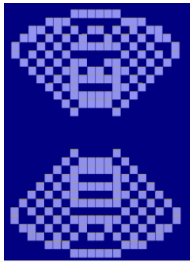
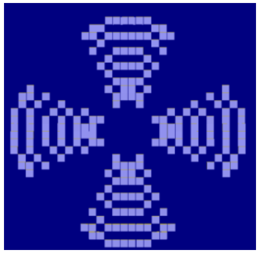
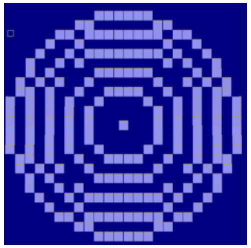
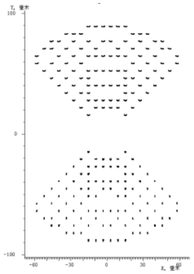
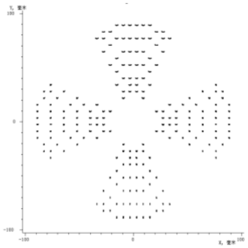
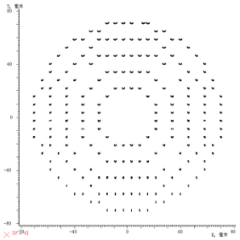
Item	Set 1	Set 2	Set 3
Wavelength	13.5nm		
Exposure field on the reticle	104mm 6mm, R=119mm		
Chief ray angle on the reticle	5.52 degree	6 degree	4.9 degree
demagnification	1/4	1/4	1/4
NA in image space	0.25	0.3	0.33

Reverse design method for illumination system







	90-degree dipole illumination	45-degree quadrupole illumination	annular illumination
Pupil facets			
Exit pupil			

The illumination uniformity is better than 2.5%.

Members of our EUV team

Yanqiu Li received the MS and PhD degrees in optics from Harbin Institute of Technology. She worked as a director of the micro- and nano-fabrication division at Institute of Electrical Engineering Chinese Academy of Science, as a senior engineer at Nikon, as an invited professor of Tohoku University of Japan, and as a frontier researcher at RIKEN of Japan. She is currently a professor of School of Optoelectronics at Beijing Institute of Technology, Beijing, China.

Zhen Cao (Speaker) received the BS degree in optoelectronic information engineering from Xi’an Technological University in 2008. He is currently works at Beijing Institute of Technology. His current interests include optical system design for EUVL.

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Qiuli Mei received her BS degree in optical information science and technology from Wuhan university of technology in 2010. She is currently a PHD candidate in the School of Optoelectronics at Beijing Institute of Technology. Her current interests involve design of illumination system and the applications of free form surface in non-imaging optics.

Yan Liu received the BS degree in Optoelectronic information engineering from Changchun University of Science and technology in 2010. He is currently a PhD candidate directed by Professor Yanqiu Li in the School of Optoelectronics at Beijing Institute of Technology. His current interests include optical system design for EUVL.

Xinli Liang received the BS degree in optical information science and technology from Nanjing University of Aeronautics and Astronautics in 2012. She is currently a MS candidate directed by Professor Yanqiu Li in the School of Optoelectronics at Beijing Institute of Technology. His current interests include design of illumination system for EUVL.

Acknowledgment

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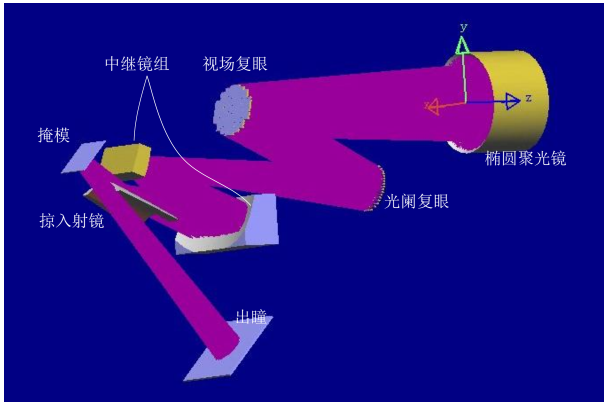
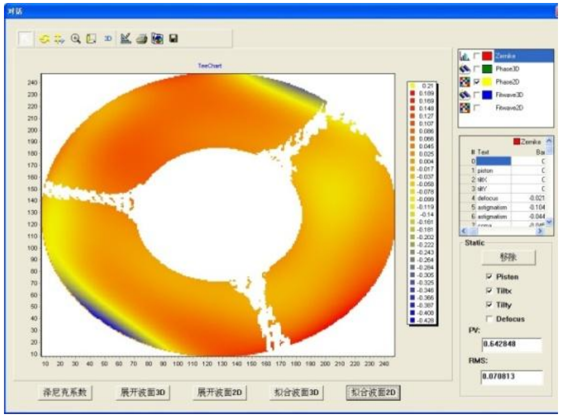
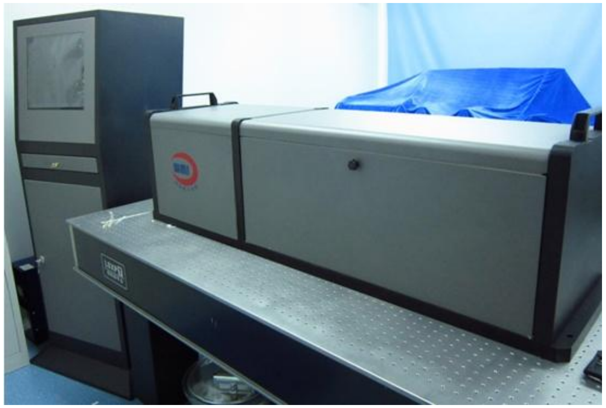


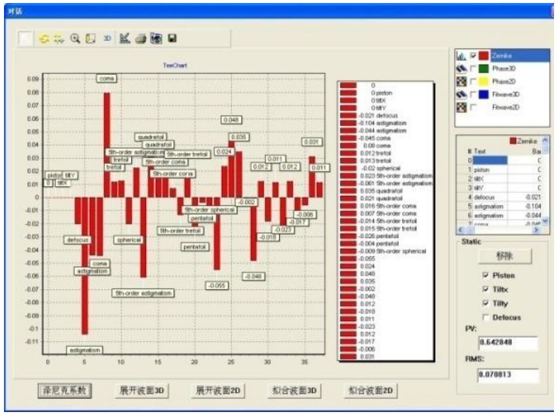


☑ Piston
☑ Tiltx
☑ Tilty
☐ Defocus

PV: 0.642848

RMS: 0.070813





☑ Piston
☑ Tiltx
☑ Tilty
☐ Defocus

PV: 0.642848

RMS: 0.070813

Thanks for your attention!