HSFET characterization of factors for imaging

Hidemi Kawai, Shunko Magoshi, Satoshi Tanaka

Evolving nano process Infrastructure Development Center, Inc.

2016 International Symposium on Extreme Ultraviolet Lithography

Hiroshima, Japan 24 - 26 October, 2016

HSFET : High-NA Small Field Exposure Tool

Scope & Outlines

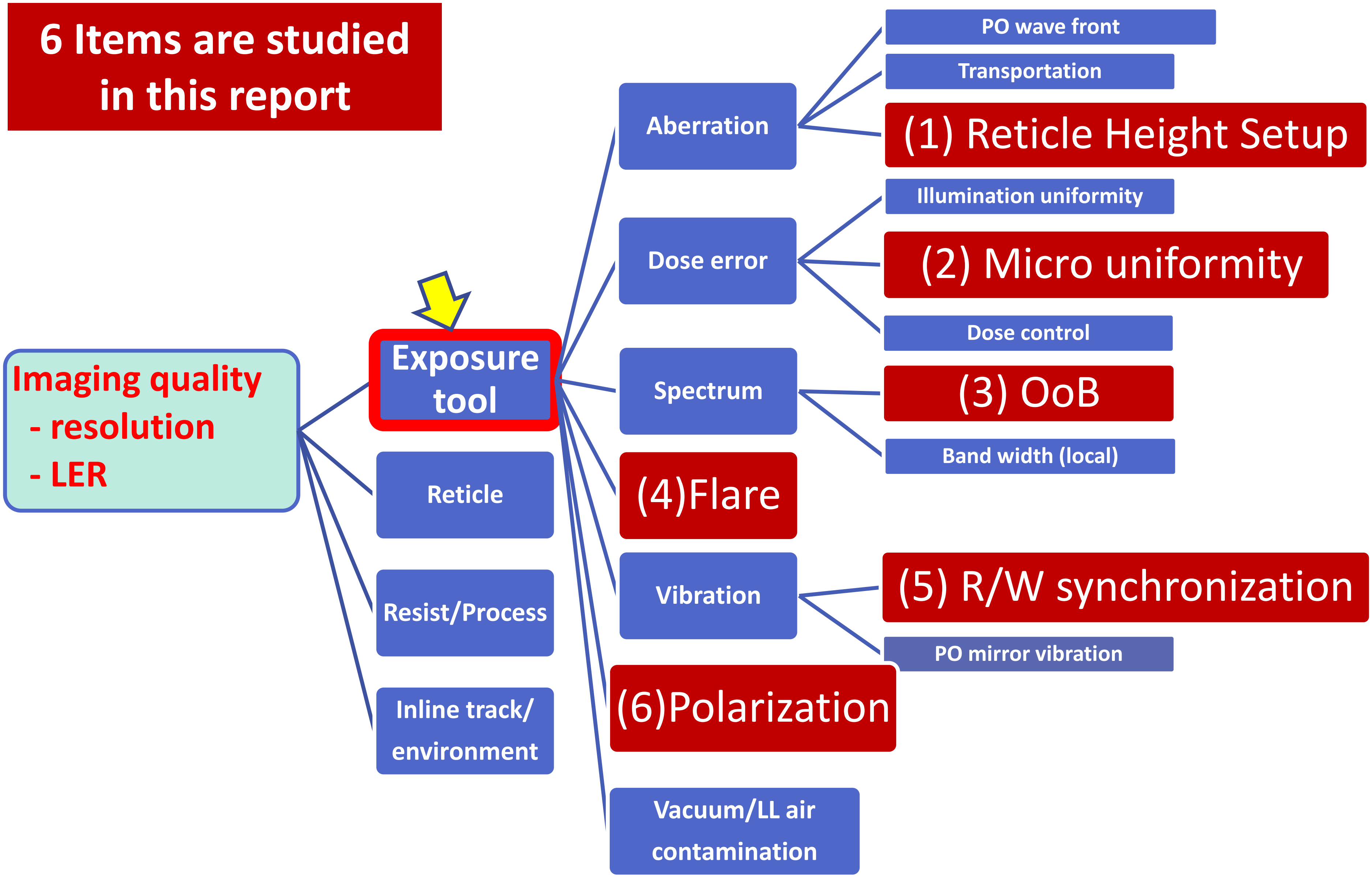
The Scope of this Study

- One of the most important roles for HSFET is to serve as a tool for exposure testing in developing photo resists. For this purpose, HSFET itself should have enough imaging performance/quality.
- There are several factors that could affect the imaging performance. To confirm the imaging performance of the tool, these factors should be categorized and characterized individually with the specific methods.

Outlines

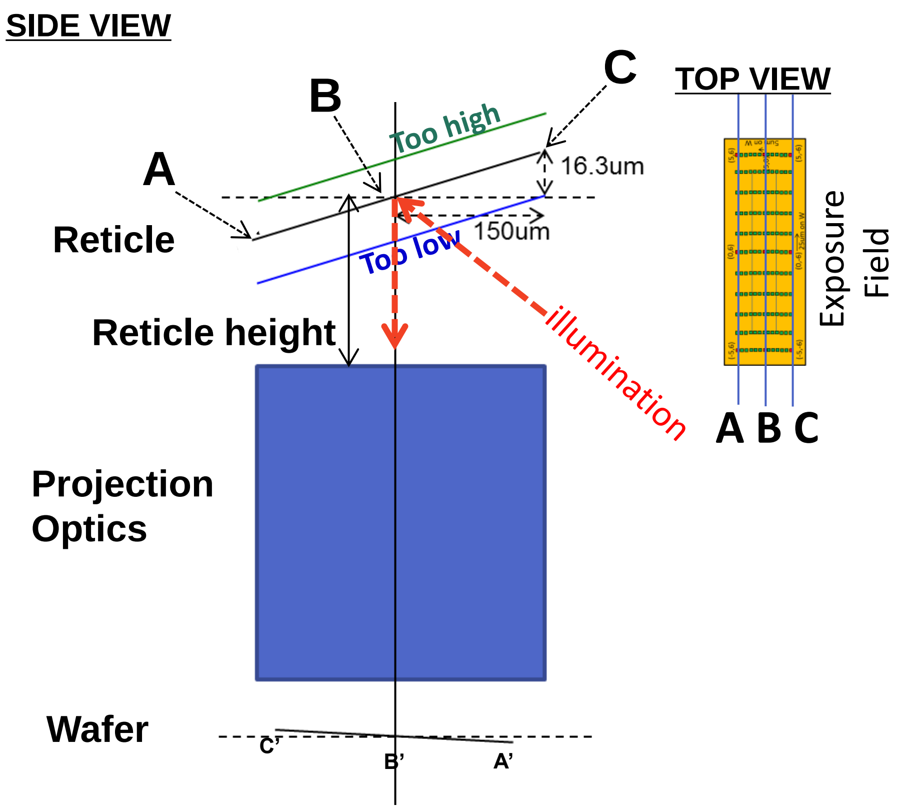
- Factor analysis diagram
- Individual experiment & result
- Summary

Factor analysis diagram for HSFET Imaging Quality



(1) Reticle height Setup (Spherical aberration)

The reticle height should be optimized for the minimum spherical aberration(mainly Z9) over the exposure field.



The principle for the verification

- When **B** is at the correct height, we should observe same amount of spherical aberration at **A** and **C**. So we planned to observe the balance of spherical aberration at **A** and **C**.
- We also utilized generally known characteristics that the best focus changes according to the pitch when spherical aberration exists.

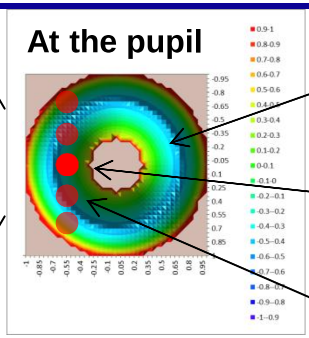
Note: Reticle is tilted by about 6 degree to introduce the illumination light and accordingly wafer is tilted about 1.2 degree by design (Scheimpflug principle).

(1) Reticle height Setup (Spherical aberration)

Detail method

L/S orientation

For finer pitch L/S, the diffracted lights go outer.

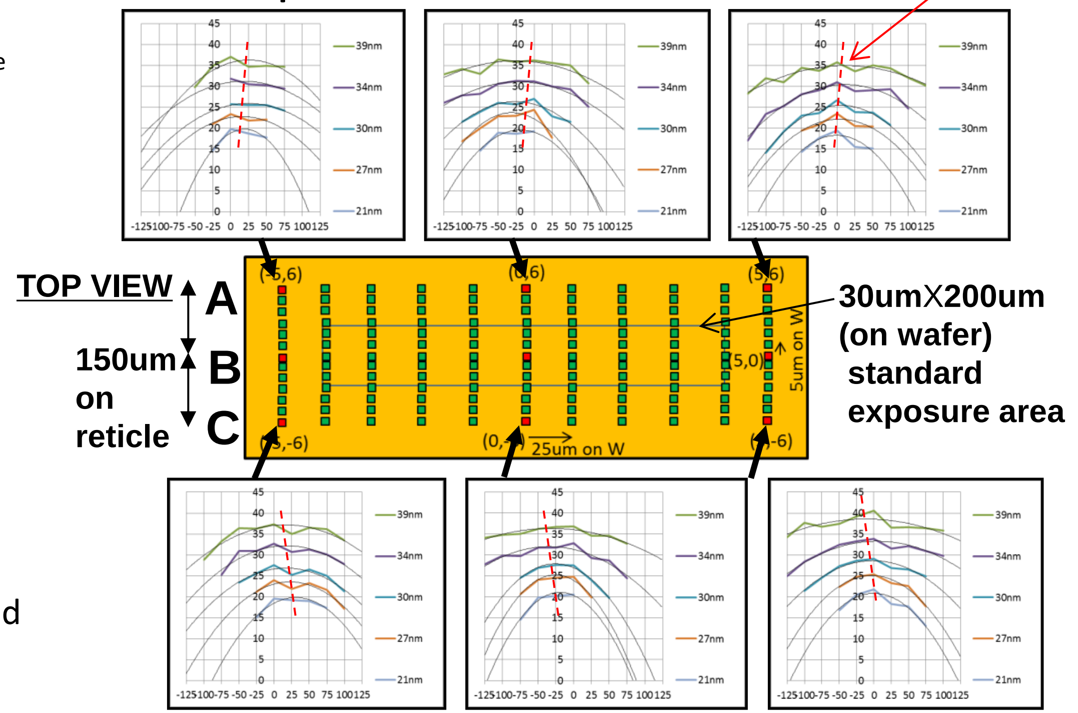


Spherical aberration phase shape

0th order (mono pole illumination aperture)

1st order

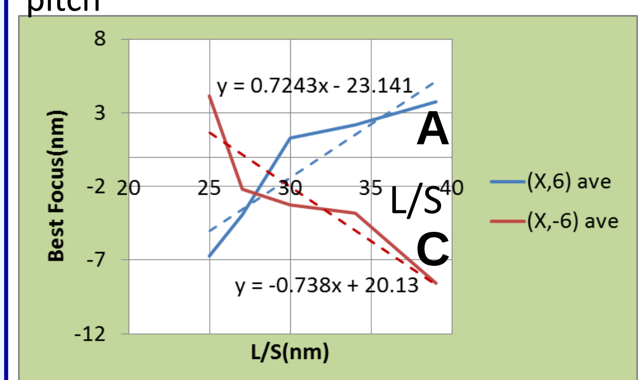
CD thru focus plots **The best focus changes according to the pitch**



3 rays(0th, +/-1st) interference method

- The diffracted lights pass through the specific positions according to L/S pitch and act as the prove of the wave front phase.
- The spherical aberration(Z9) is locally approximated by focus error(Z4). Therefore, if there is spherical aberration, the best focus changes according to the L/S pitch. We measured the best focus for several pitch L/S and saw the balance of the trend between A and C.

The best focus changes according to the pitch



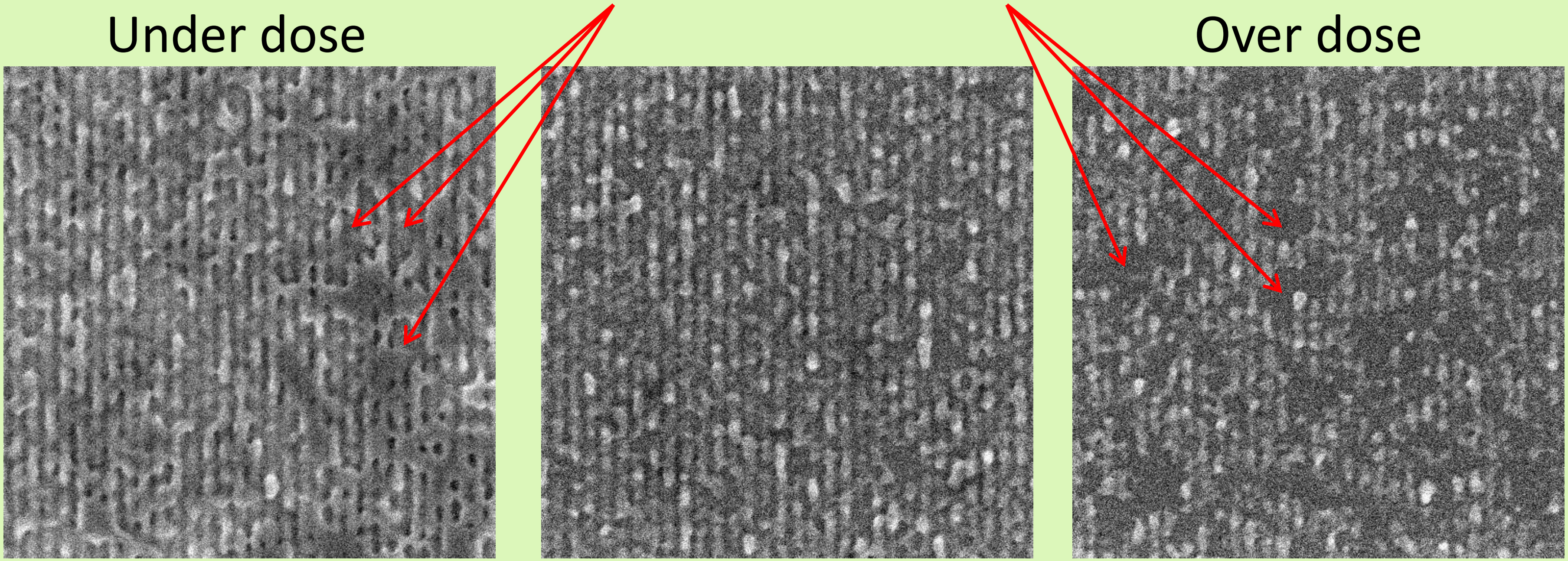
- **The variation of best focus according to the pitch is balanced between A and C.**
- **The height at B is calculated to be about 0.15um off from the correct height. This corresponds to Z9 rms 0.004nm at B.**

EIDEC

(2) Micro uniformity

<u>**Micro modulations**</u> are observed on the uniform pattern area.

Under dose | Over dose



11nm L/S H :Dipole illm : Positive tone resist

- The random modulation in addition to L/S patterns looks to be disturbing factor for good resolution.
- If speckle, it might be coming from **mask surface roughness** or it might be related to some **tool factors like illumination conditions**.
- We tested these possibilities by exposed resist image analysis.

(2) Micro uniformity

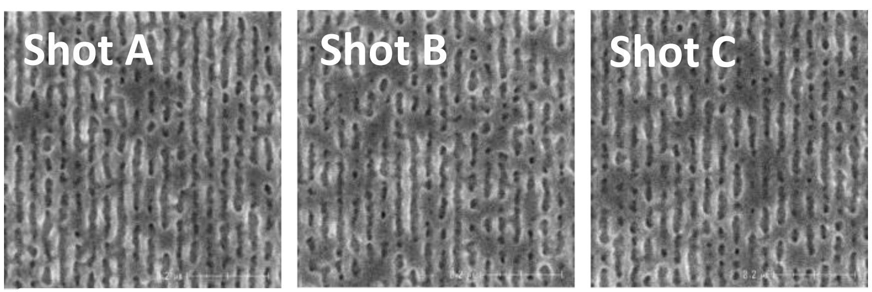
■ Is the modulation coming from **Mask Surface Roughness**?

- When Mask Surface Roughness is large enough, it could cause the **speckle** that affects the line edge roughness.

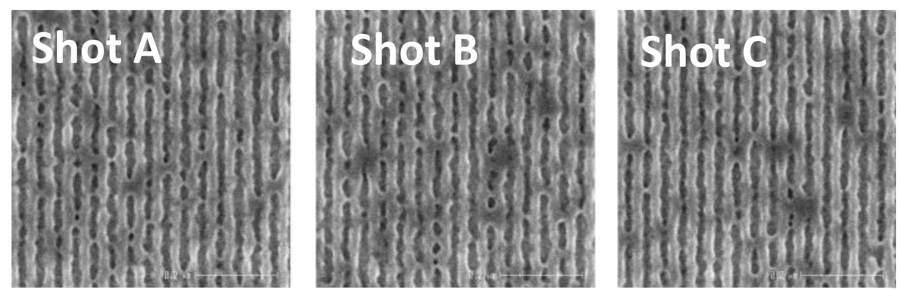
Ref: A. V. Pret, et.al. , "**Evidence of speckle in extreme-UV lithography**", OPTICS EXPRESS, Vol. 20, No. 23, 2012

- Comparison between different exposure shots on a wafer but the same location on the reticle. If the speckle is coming from the reticle, we should see similar modulation pattern between the shots.

18nm L/S



22nm L/S

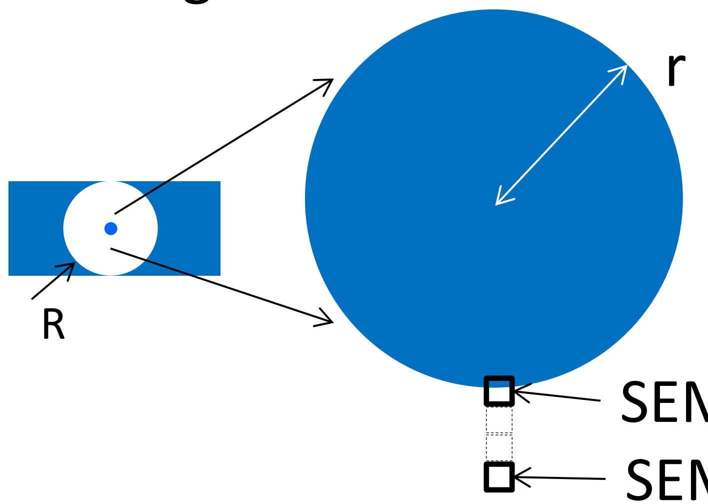


- **The modulation patterns do not correlate between the shots. It does not look like that the modulation is coming from the speckle due to the reticle.**

(2) Micro uniformity

■ Is the modulation coming from **tool factors like illum. conditions**?

➢ A good method to see the speckle is resist exposure with the dosage a little lower than Eth.

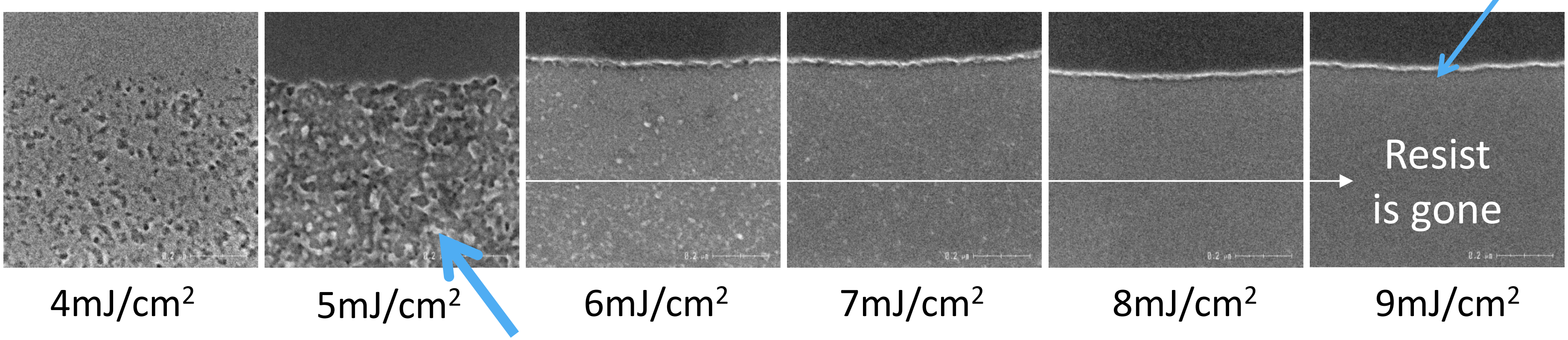


r=5um (on wafer) absorber
in R=100um multilayer area

SEM pictures below (680nm square)

SEM pictures in the following page

Resist is remaining

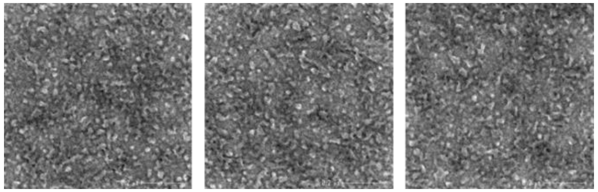


4mJ/cm^2 | 5mJ/cm^2 | 6mJ/cm^2 | 7mJ/cm^2 | 8mJ/cm^2 | 9mJ/cm^2

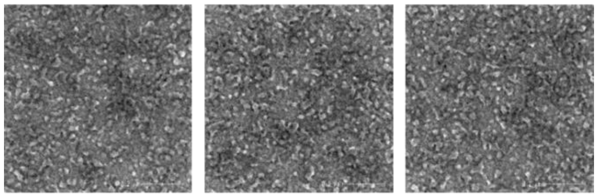
Good for **PSD(Power Spectral Density)** analysis

(2) Micro uniformity

Annular illumination aperture

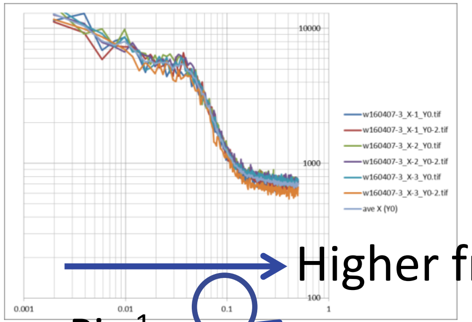


Different exposure shots

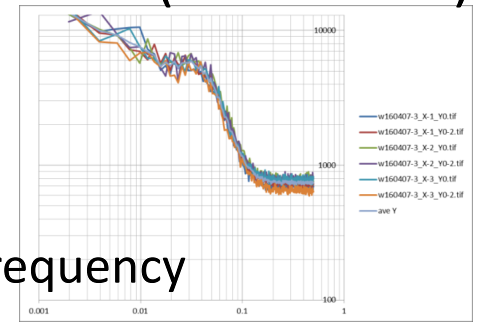


PSD

PSD (X direction)



PSD (Y direction)

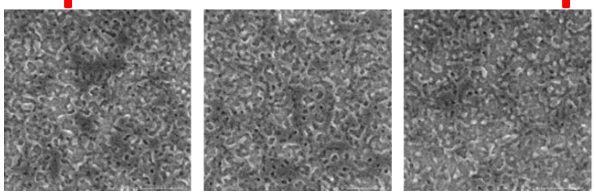


Higher frequency

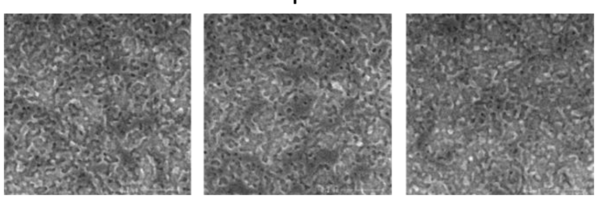
Pix-1

Corresponding to 0.1cycle/pix (about pitch13nm)

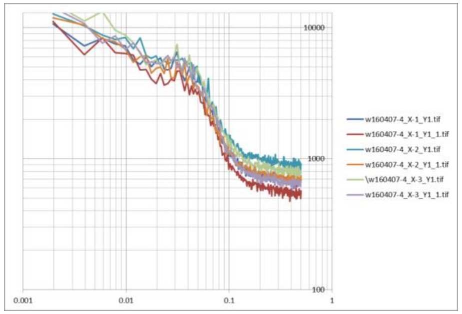
Dipole illumination aperture

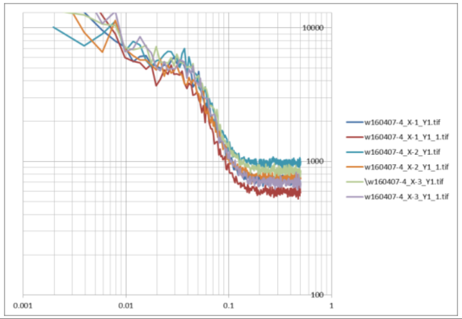


Different exposure shots

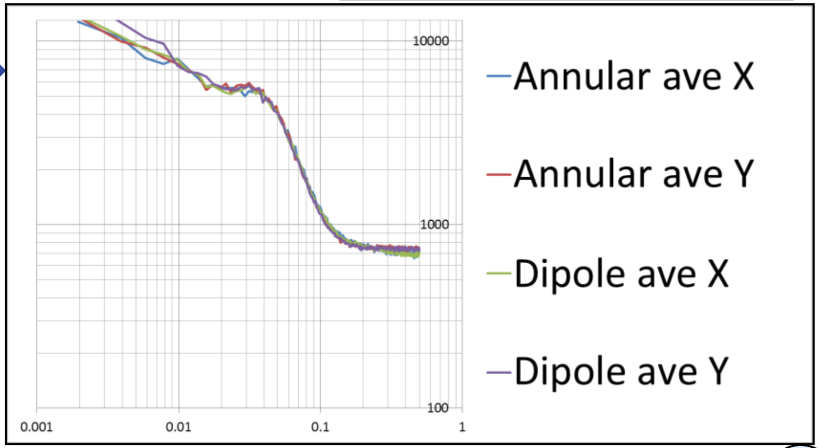


PSD





Each averaged

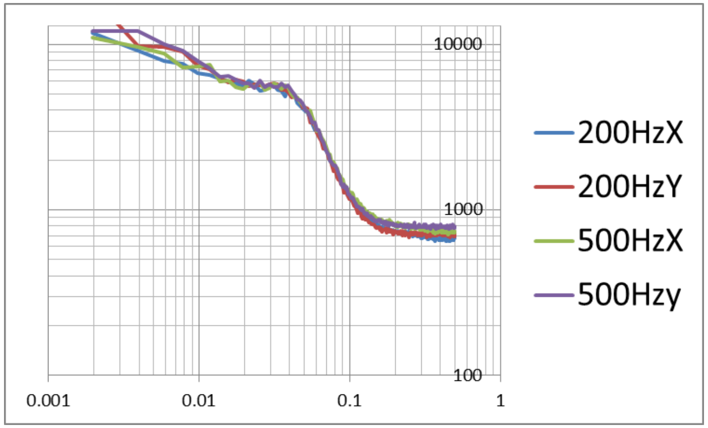


- **No difference between illumination apertures**

(2) Micro uniformity

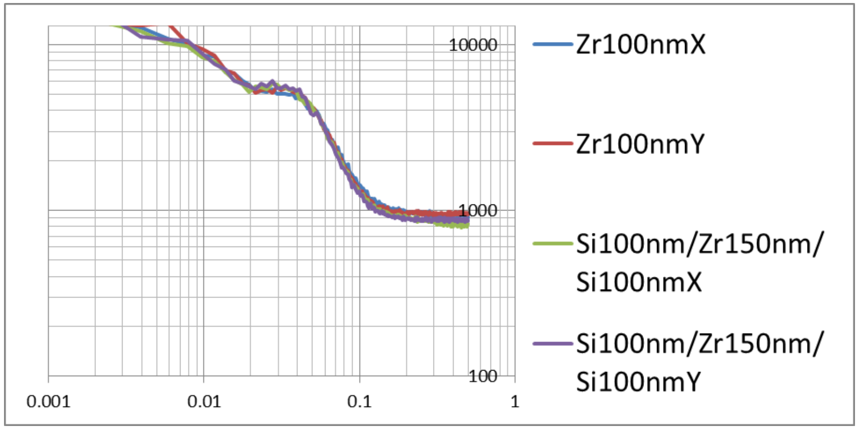
Similarly, further test with other conditions were conducted.

Light source frequency



No difference

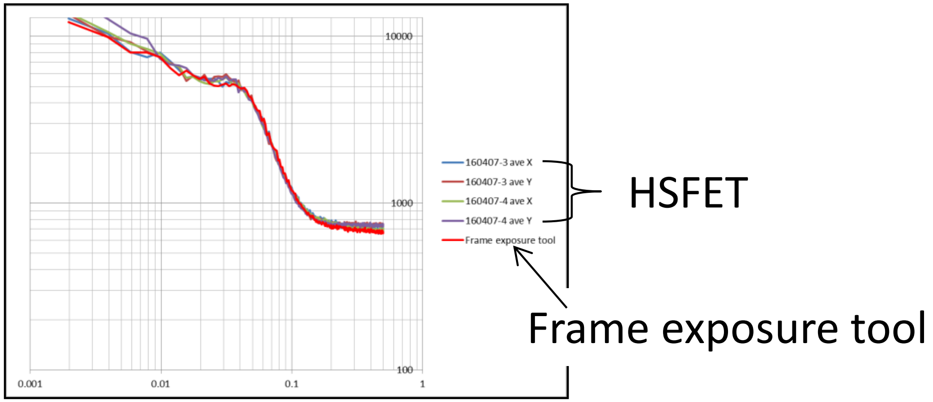
SPF difference



No difference

Stand alone "EUV frame exposure tool" v.s. HSFET

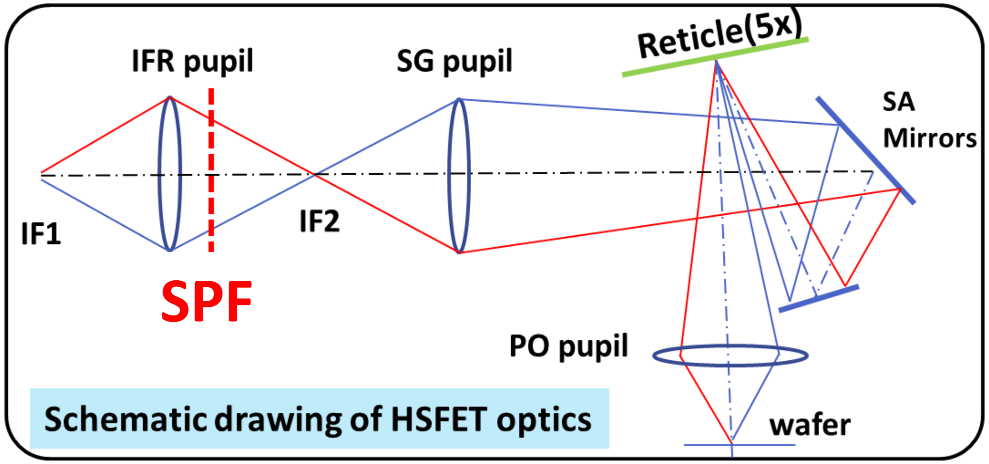
Note: Frame exposure tool is a stand alone tool to provide EUV exposures on a wafer mainly for measuring resist sensitivity curve.



No difference

➤ **Finally, we concluded that this random modulation is not HSFET tool specific.**

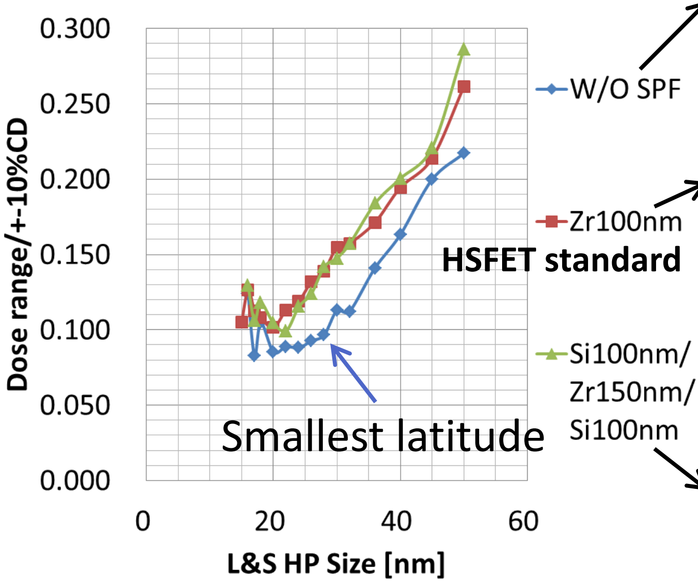
(3) OoB



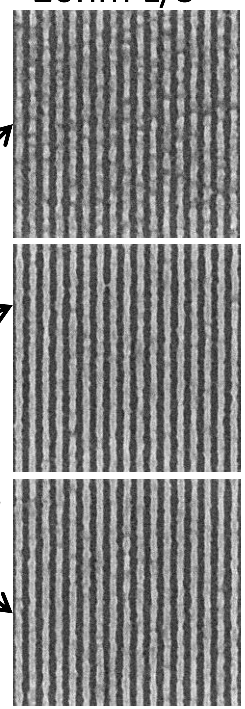
SPF is located close to the IFR pupil. We replaced the SPF and compared the SEM image quality and the exposure latitude.

- Exposure latitude is calculated from measured CD-dose data

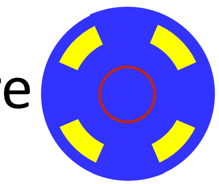
Exposure latitude



20nm L/S

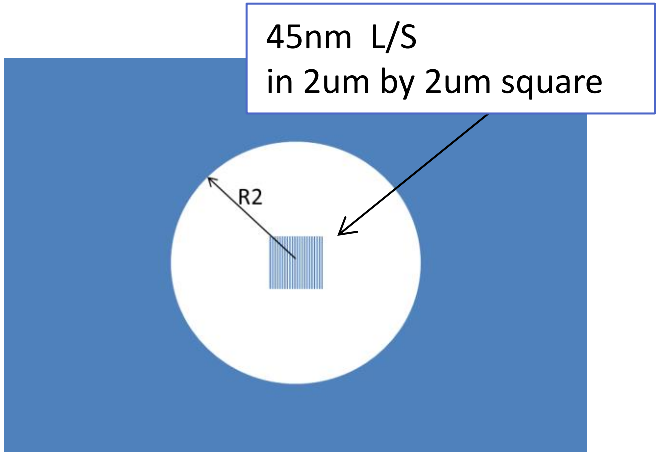


Quadrupole aperture

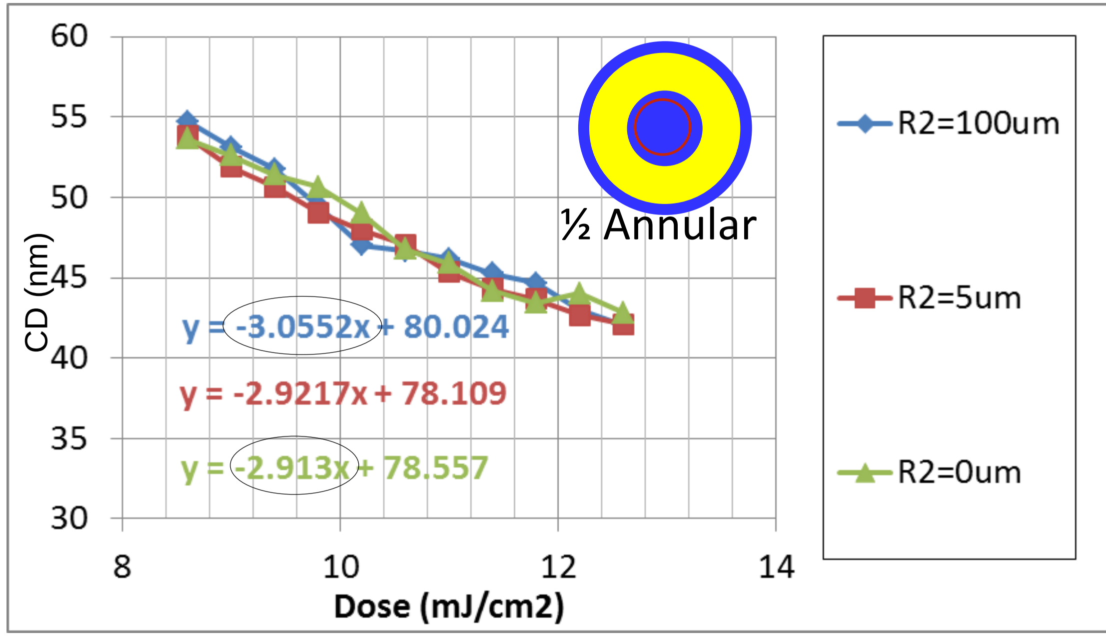


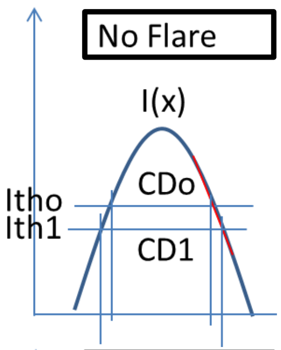
- **Noticeable difference is seen between <u>no SPF</u> and <u>Zr100nm</u>.**
- **Little difference between <u>Zr100nm</u> and <u>Si100nm/Zr150nm/Si100nm</u>.**
- **HSFET standard SPF seems to be good enough.**

(4) Flare



Absorber all around



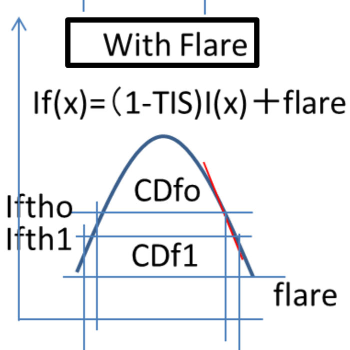


Itho = CDo

Ith1 = CD1

$\Delta CD = \Delta Ith / (dI/dx) * 2$

$\Delta CD / \Delta Ith = 2/(dI/dx)$



Iftho = CDfo

Ifth1 = CDf1

$\Delta CDf = \Delta Ifth / (dIf/dx) * 2$

$= \Delta Ifth / ((1-TIS)(dI/dx)) * 2$

$\Delta CDf / \Delta Ifth = 2/((1-TIS)(dI/dx))$

$$\frac{\Delta CD/\Delta Ith}{\Delta CDf/\Delta Ifth} = 2.91/3.06 = 0.953$$

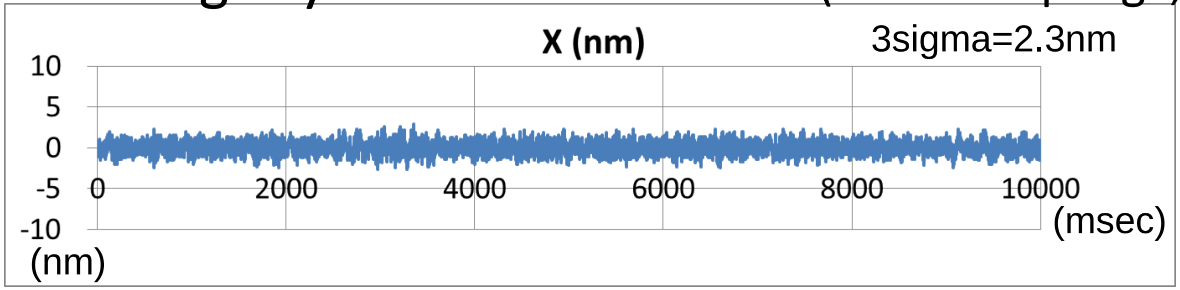
On the other hand,

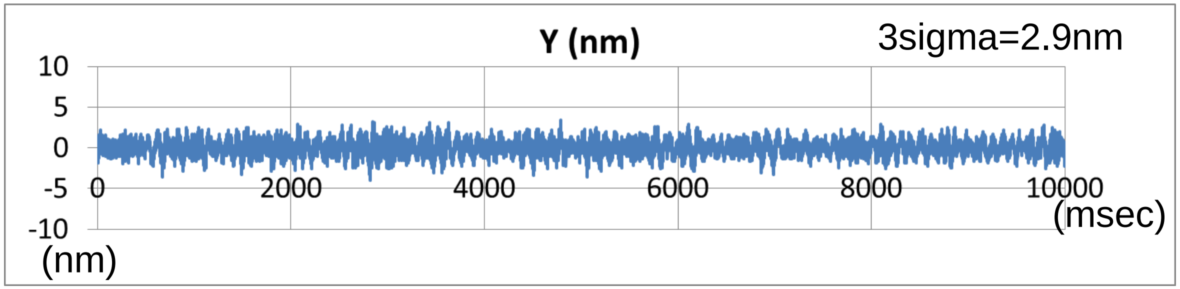
$$\frac{\Delta CD/\Delta Ith}{\Delta CDf/\Delta Ifth} = \frac{2/(dI/dx)}{2/((1-TIS)(dI/dx))} = (1-TIS)$$

- **flare ≤ TIS ≈ 4.7%**
  (spec: flare< 5%)

(5) R/W synchronization

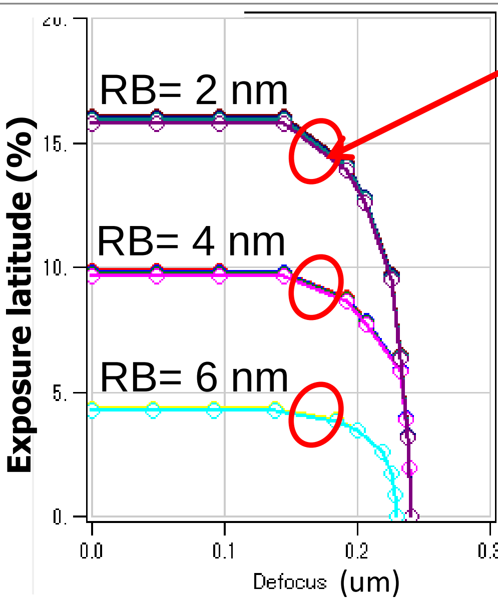
Reticle/Wafer stage synchronization data (1kHz sampling , 10sec duration)





Simulation

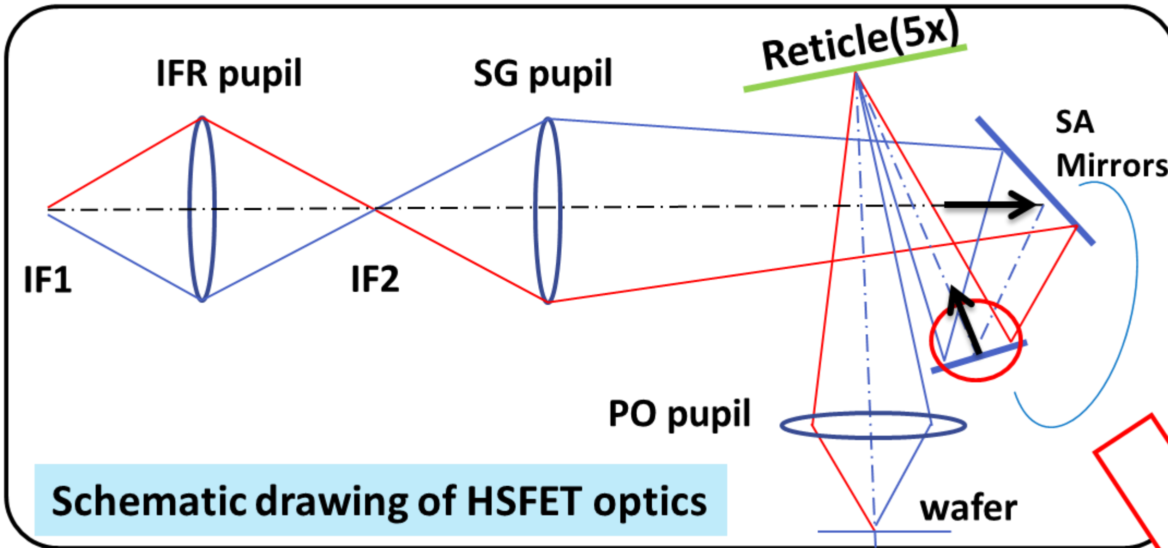
- 11nm L/S
- Dipole illumination
- RB = Resist Blur (Gaussian, sigma)



Stage vibration=0.5~2nm(3sigma)

- **Synchronization error is small enough.**
- **We should not see the degradation due to the synchronization error.**

(6) Polarization



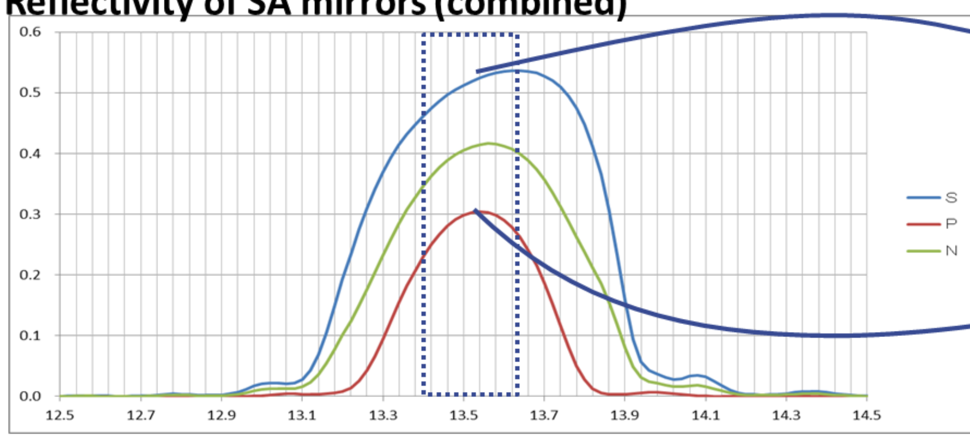
Schematic drawing of HSFET optics

CRA : 6deg (approx.)

Incident angle : 23-28deg

SA: Spot Adjust
SG: Spot Generate
IFR: IF Relay

Reflectivity of SA mirrors (combined)

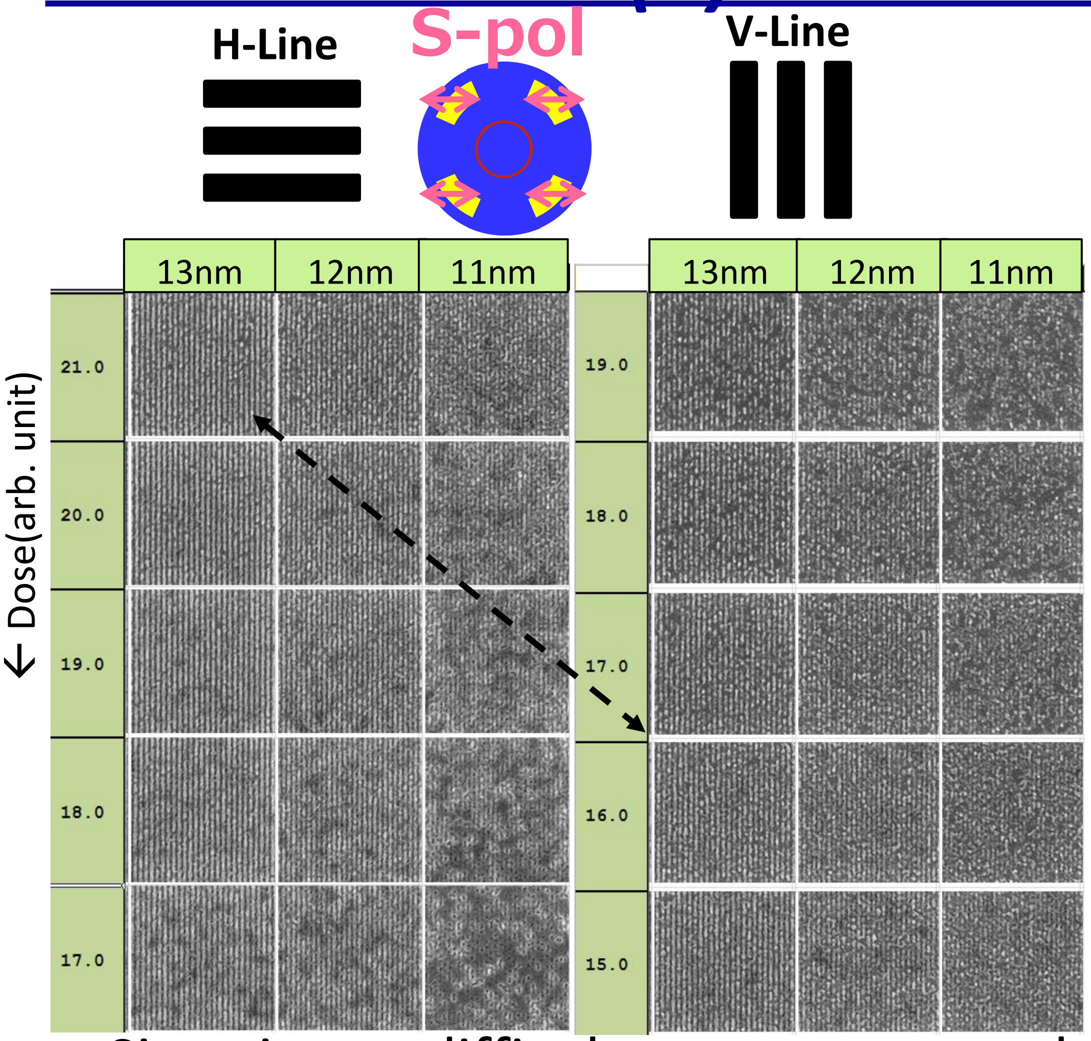


S-pol > P-pol

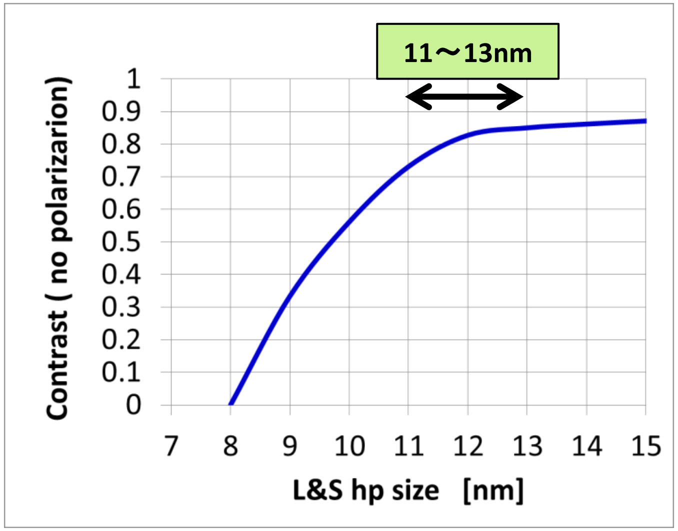
✓ SA1/SA2 Mirrors work as "Psuedo" polarizer.

Reference: Satoshi Tanaka et al. "**Current development status of HSFET (High NA Small Field Exposure Tool) in EIDEC**", *Proc. SPIE* 9776, Extreme Ultraviolet (EUV) Lithography VII, 97761N (March 18, 2016)

(6) Polarization

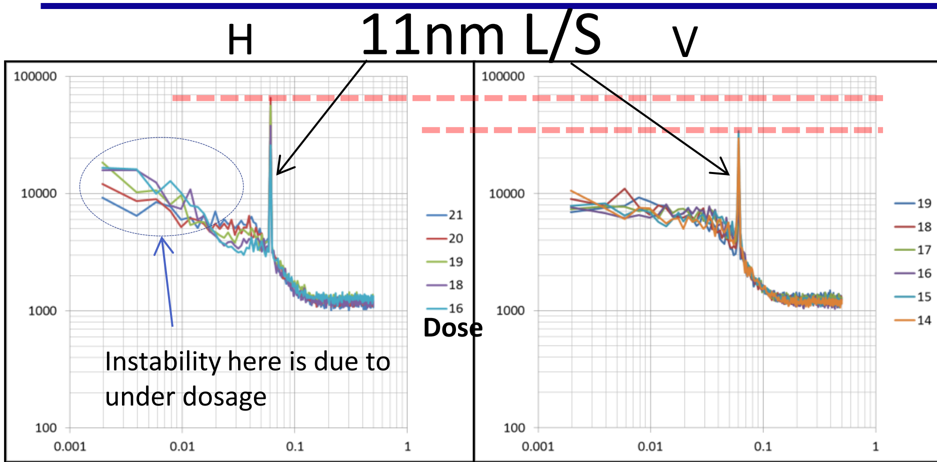


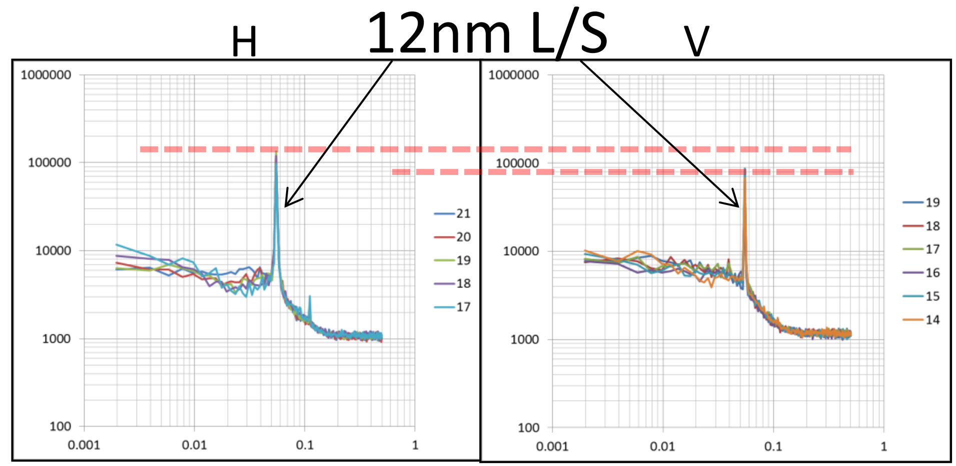
- Quadrupole aperture is used to expose V and H lines in a same shot.
- Best dose difference between V and H is due to the shadowing effect.

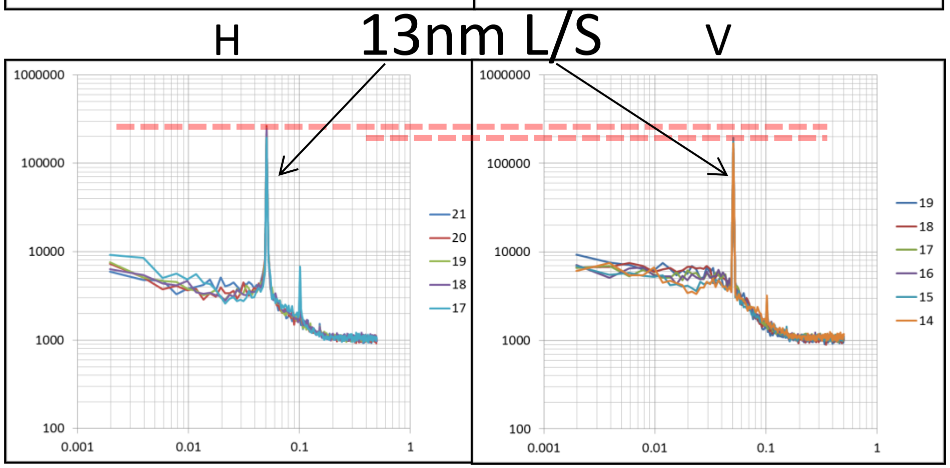


- Since it was difficult to get exposure latitude by measuring the CD reliably enough in this fine region, we performed PSD analysis to compare the strength of modulation (next page).

Polarization







- **The PSD difference between H and V at each L/S frequency is thought to be due to the polarization difference. H pattern can be applied as needed.**

Summary

- Several tool factors that could affect the imaging performance were characterized.
- The factors reported are reticle height(system spherical aberration), micro uniformity, OoB, flare, R/W synchronization, and polarization.
- So far there are no factors found that are affecting the imaging performance significantly.

Acknowledgements

We would like to thank to ;

Zygo : HSFET optics design and manufacturing & integration & support

Canon : HSFET body & system manufacturing & integration & support

Ushio : HSFET Xe DPP source system manufacturing & support

DNP and DTF : HSFET reticle manufacturing

and all EIDEC members

This work had been supported by

METI (Ministry of Economy, Trade and Industry)

and

New Energy and Industrial Technology Development Organization (NEDO).