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Precision Equipment Company

Flare Calculation on EUV Optics

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Precision Equipment Company

NIKON CORPORATION

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Overview

- Flare treatment
  - Definition and notation
  - Conventional method
  - New method
    - Multilayer extinct effect
    - Obscuration of scatter
    - Combine PSFs *not* via system-PSD
    - Two PSFs, for flare and TIS
- Results of flare evaluation
  - PO #1 – Kirk flare test, flare correction (OPC)
  - PO #2 – Kirk flare test

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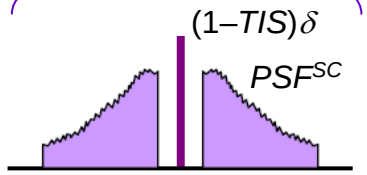
Definition and notation

Image Intensity

$$I(\vec{x}) = \left\{(1-TIS)\delta(\vec{x}) + PSF^{SC}(\vec{x})\right\} \otimes I_0(\vec{x})$$
$$= (1-TIS)I_0(\vec{x}) + PSF^{SC}(\vec{x}) \otimes I_0(\vec{x})$$
$$= \underbrace{(1-TIS)I_0(\vec{x})}_{\text{Uniform intensity decrease}} + \underbrace{\iint_{\infty} PSF^{SC}(\vec{x}-\vec{x}')I_0(\vec{x}')d\vec{x}'}_{\text{Image blur}}$$

PSF_{Flare}



$= (1-TIS)I_0(\vec{x}) + F \cdot PD$
DC-flare model
F: DC flare
PD: pattern density

***I*(*x*)**: Flared image intensity
$I_0(x)$: Original intensity
TIS: Total integrated scatter
PSF^{SC}: PSF contributing flare; component reaching wafer

TIS

$$TIS = \iint_{\infty} PSF^{SC0}(\vec{x})d\vec{x} = \int_{\infty} 2\pi r \cdot PSF^{SC0}(r)dr$$

derived from PSDs

PSF^{SC0}: PSF contributing flare; component as scattered, $\neq PSF^{SC}$

Definition and notation

Flare

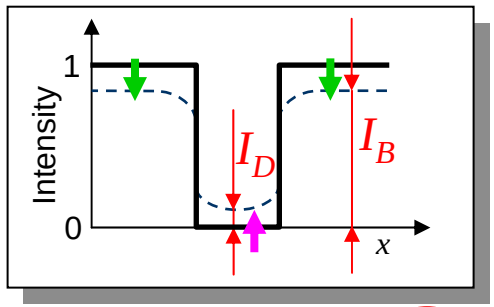
$$F(\vec{x}_0) = \iint_{\text{bright field}} PSF^{SC}(\vec{x} - \vec{x}_0)\,d\vec{x}$$

Kirk flare (KF)

$$KF = \frac{I_{D\min}}{I_{B\max}},$$

$$\begin{cases} I_D(\vec{x}_D) = \iint_{\text{bright field}} PSF^{SC}(\vec{x} - \vec{x}_D)\,d\vec{x} \\ I_B(\vec{x}_B) = (1 - TIS) + \iint_{\text{bright field}} PSF^{SC}(\vec{x} - \vec{x}_B)\,d\vec{x} \end{cases}$$

$I_D(x_D)$: Intensity at dark pad x_D
$I_B(x_B)$: Intensity at bright area x_B



Flare effect on image can be expressed using **TIS** & **PSF^{SC}**. "**Kirk flare**", which can be experimentally observed as an intensity ratio (= dimensionless), does not equal to "**flare**."

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Conventional method

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- Flare calculation from power spectral density (PSD)

$$PSD_1(f_1), PSD_2(f_2), \cdots, PSD_6(f_6)$$

Mirror PSDs

$$\lambda f_i \approx \theta_i \approx \frac{r_i}{z}$$

Not adequate at a larger scatter angle

$$SystemPSD(f) = \sum_{i=1}^{6} {\alpha_i}^2 PSD_i(\alpha_i f_i)$$

equivalent system PSD on pupil

Not adequate at a larger scatter angle

$$F(r) \equiv PSF^{SC}(r) = \left(\frac{4\pi}{\lambda^2 z}\right)^2 SystemPSD\left(\frac{r}{\lambda z}\right)$$

PSF by scattering

$$Flare = \int_{r \text{ in bright area}} 2\pi r \cdot F(r) dr$$

"Flare" component should be calculated from another PSF, *not* as-scattered.

$$TIS = \int_{\infty} 2\pi r \cdot F(r) dr$$

This infinite integration cannot be carried out under linear domain conversion.

Problems:
- No scatter extinction effect
- No obscuration effect
- Linear conversion twice (small angle approximation)
- PSF domain limited at a finite distance (not infinity)
- Same PSF for flare & TIS

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New method: TIS

- TIS calculation from power spectral density (PSD)

$$PSD_1(f_1), PSD_2(f_2), \cdots, PSD_6(f_6)$$

Mirror PSDs

$$(\lambda f_i = \sin\theta_i)$$

$$PSD'_i(f_i) = PSD_i(f_i) \cdot Ext_i(\theta_i)$$

Scatter extinction by ML

$$F_i^0(r) = \beta'_i(r)\left(\frac{4\pi}{\lambda^2 z_i}\right)^2 PSD'_i\left(\frac{r}{\lambda\sqrt{z_i^2 + r^2}}\right)$$

Non-linear conversion, *not* via the SystemPSD.

Mirror PSFs

$$PSF^{SC0}(r) = \sum_{i=1}^{6} F_i^0(r)$$

PSF by scattering, component as scattered

$$TIS = \int_{\infty} 2\pi r \cdot PSF^{SC0}(r)\,dr$$

Consideration:
- Scatter extinction effect included
- Approximation released partially (esp. between finite and infinite)
- Not via system PSD

New method: Flare

- Flare calculation from power spectral density (PSD)

$$PSD_1(f_1), PSD_2(f_2), \cdots, PSD_6(f_6)$$

Mirror PSDs

Scatter extinction by ML

$$PSD_i''(f_i) = PSD_i(f_i) \cdot Ext_i(\theta_i) \cdot Obs_i(\theta_i) \qquad (\lambda f_i = \sin\theta_i)$$

Obscuration

$$F_i(r) = \beta_i''(r)\left(\frac{4\pi}{\lambda^2 z_i}\right)^2 PSD_i''\left(\frac{r}{\lambda\sqrt{{z_i}^2 + r^2}}\right)$$

Non-linear conversion

Mirror PSFs

$$PSF^{SC}(r) = \sum_{i=1}^{6} F_i(r)$$

PSF by scattering, component reaching wafer

$$Flare = \int_{r \text{ in bright area}} 2\pi r \cdot PSF^{SC}(r)\,dr$$

Flare component on wafer

Consideration:
- Obscuration effect included
- Separate PSF for flare and TIS

Multilayer extinct effect

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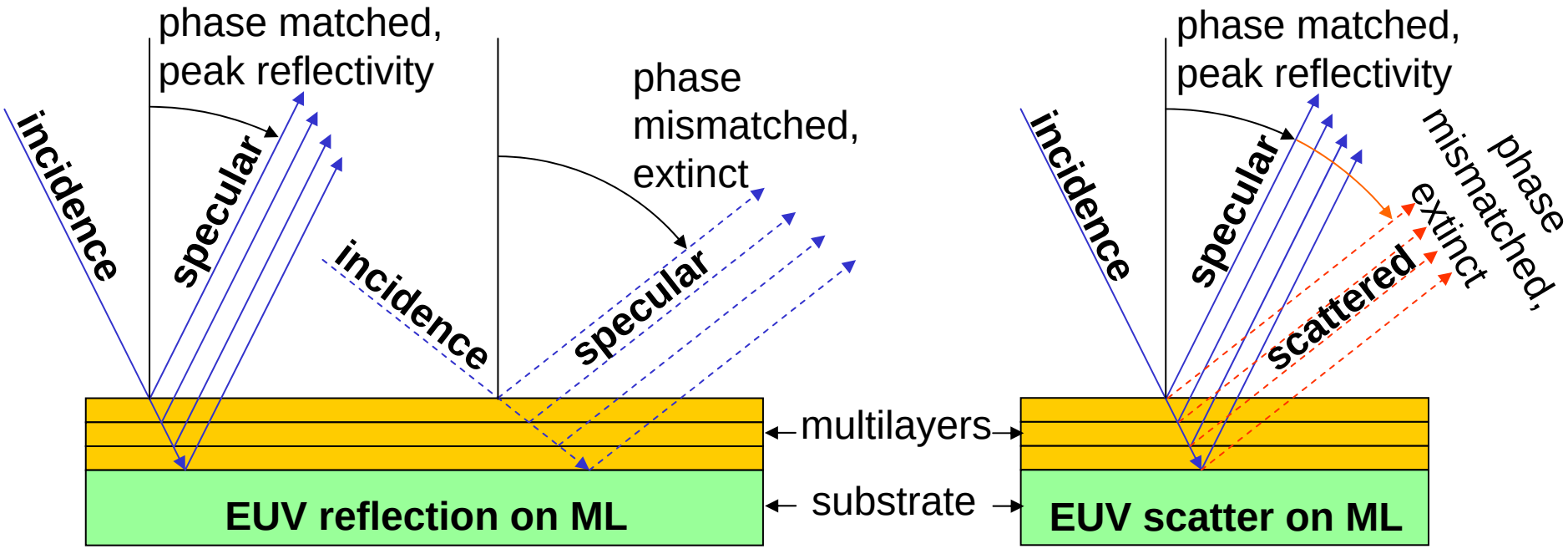
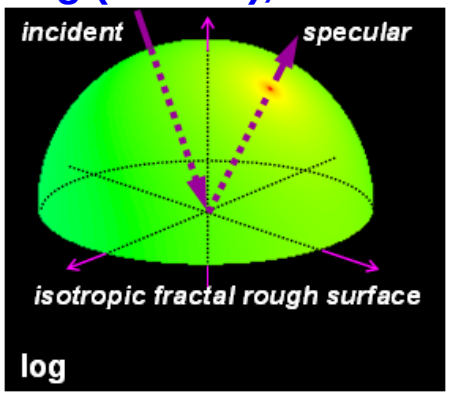
- Scatter extinction by interference in multilayers (MLs)

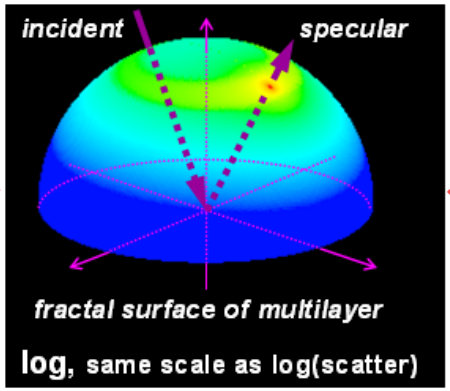
E.M.Gullikson, *SPIE* 3331



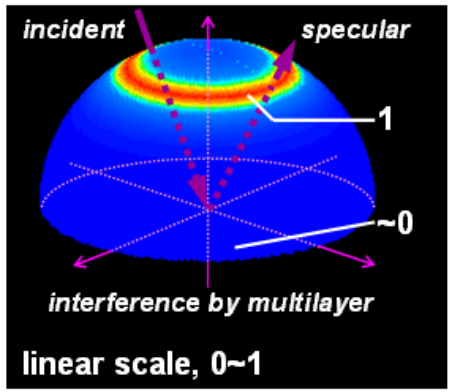
log (scatter), no ML



log (extinct * scatter)

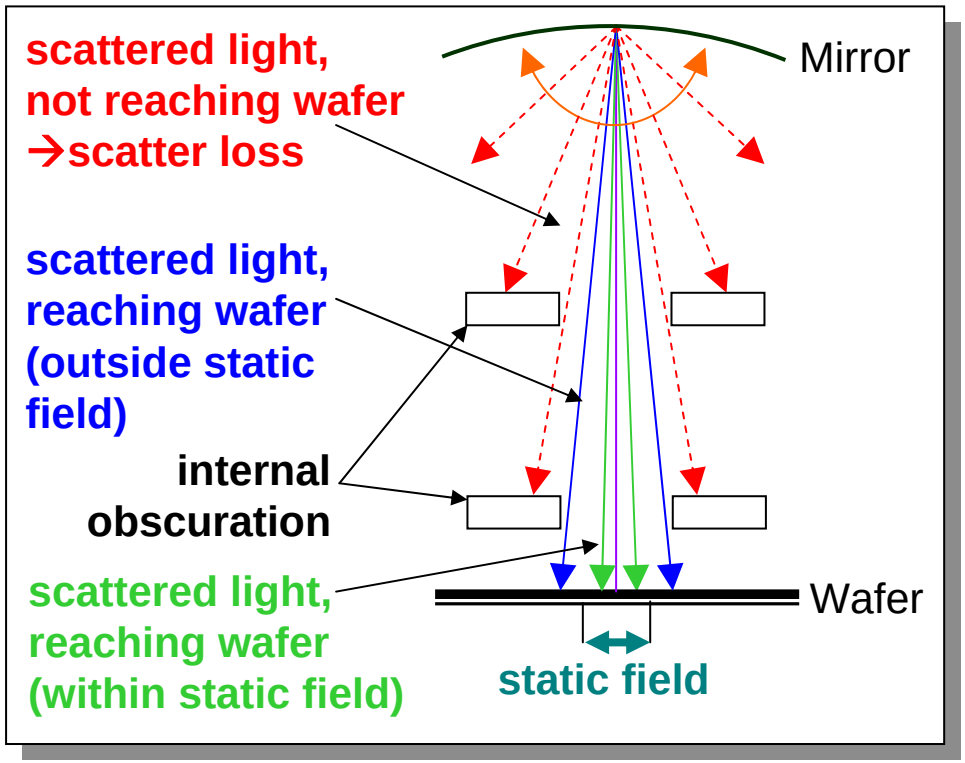


ML extinct coeff.



Obscuration of scatter

- Obscuration ratio (of component reaching wafer to as-scattered component)



scatter ray tracing

- 5,000,000 rays were thrown away from the light source per condition.
- Internal obscuration was modeled.
- About 1,500,000 rays reached the exposure field on the reticle plane.
- Each ray created scatter light on each PO mirror in random direction at each scatter angle (including *specular* lights, of course 100% of them can reach wafer).

Internal obscuration: apertures, mechanics, mirror coating areas and a flare stop.

Total ~1 billion rays were thrown away. “Obscuration ratios” (how many scatter rays, out of rays leaving reticle, reach wafer) for each scatter angle for each PO mirror were obtained.

Combine PSF *not* via system PSD

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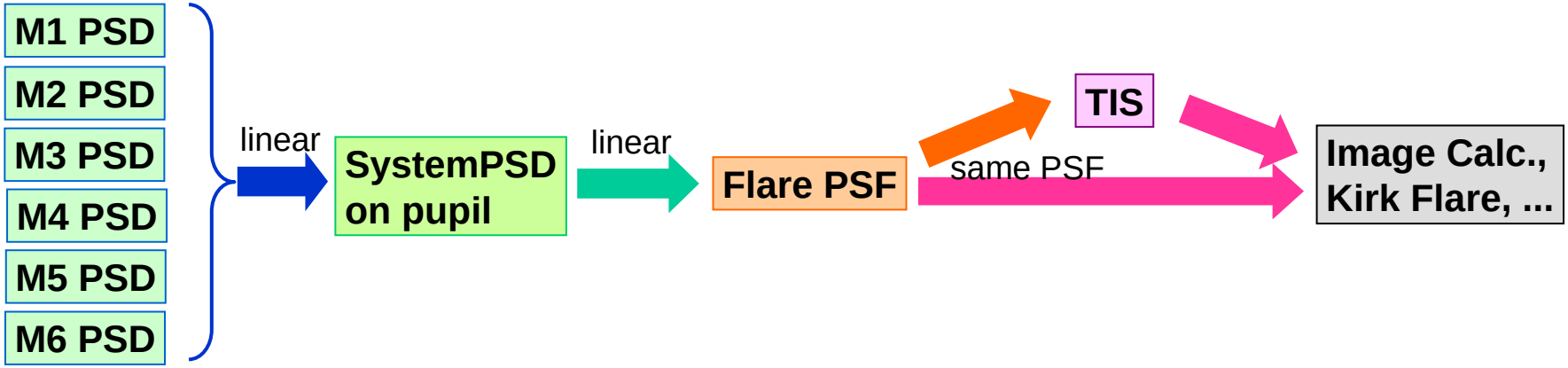
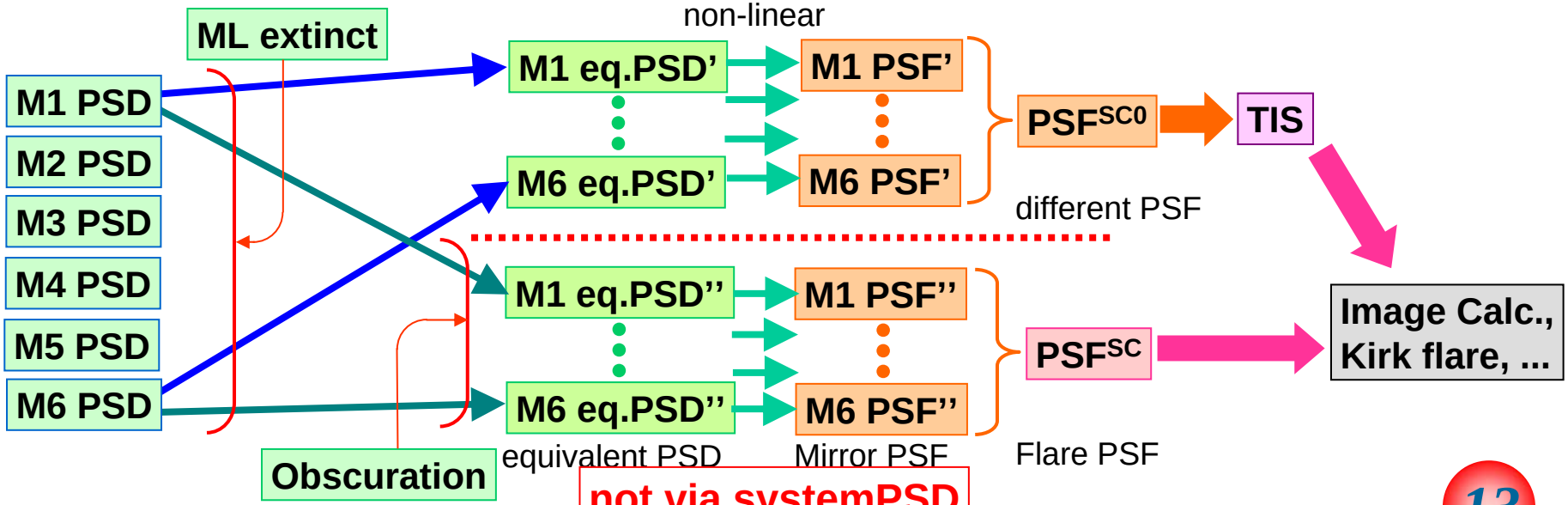
Conventional conversion

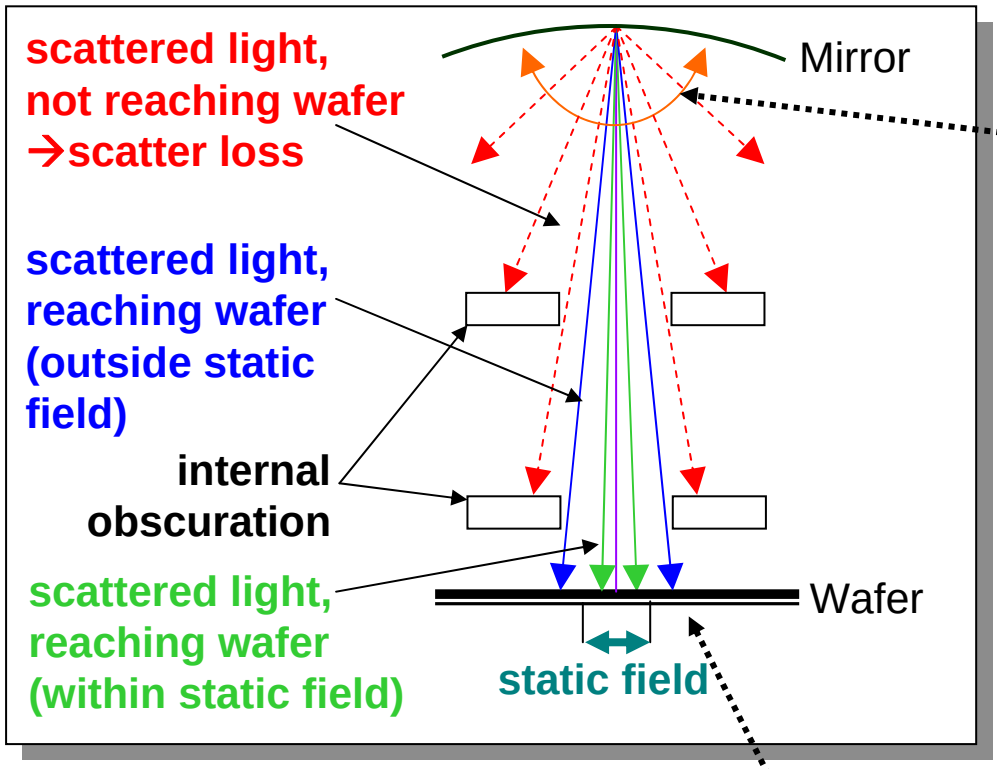


New conversion



Two PSFs, for flare and TIS

- TIS and PSF^{SC} are derived from PSF^{SC0}



PSF^{SC0}

PSF as scattered:
created from mirror PSDs
→TIS is obtained by integration of this to infinity.

apply all obscurations

total integration
(constant)

PSF as reaching wafer:
applied all obscurations' effect to PSF^{SC0}
→convolution with $I_0(x)$.

PSF^{SC}

$$TIS \equiv \int_{\infty}^{\infty}\int PSF^{SC0}(\vec{x})d\vec{x}$$

characteristic of PO

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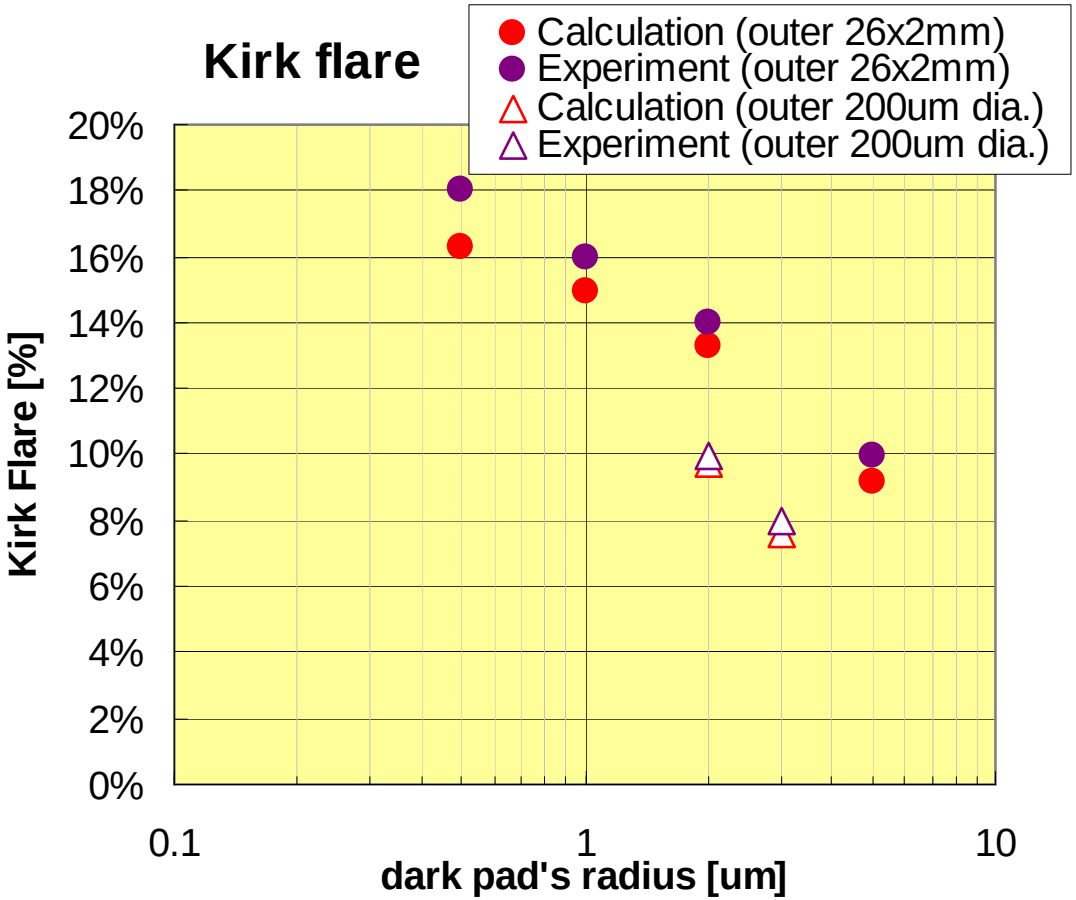
EUV1 PO #1 flare evaluation

By courtesy of Selete

- Kirk-flare measurement



For the smallest pad, the apparent flare seems to be affected also by wavefront error. (~1%)

Kirk flare measurement and calculation agree well with each other by ~1% error.

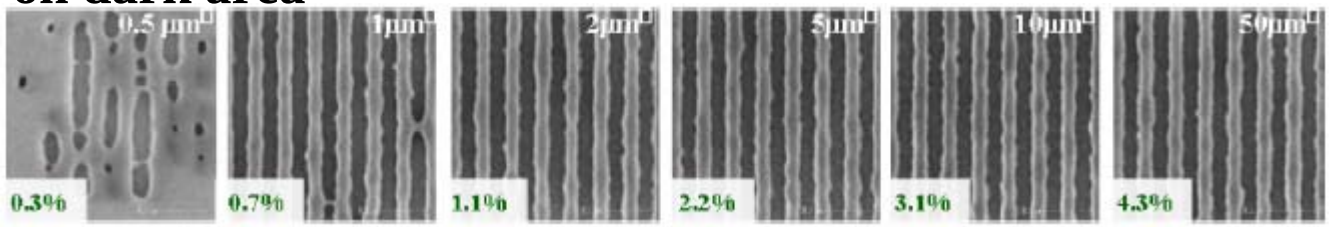
EUV1 PO #1 flare evaluation

- Printed CD variation

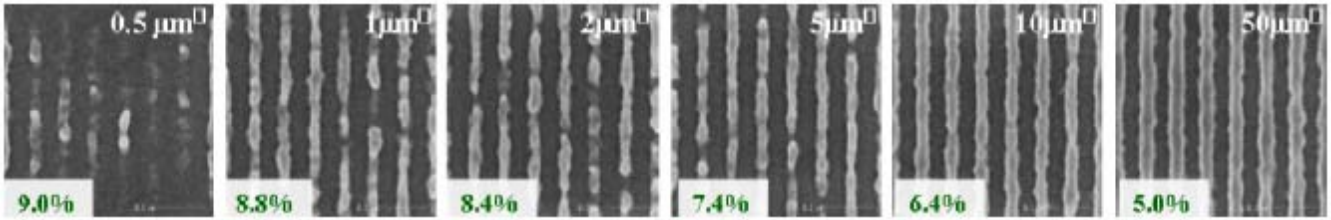
By courtesy of Selete

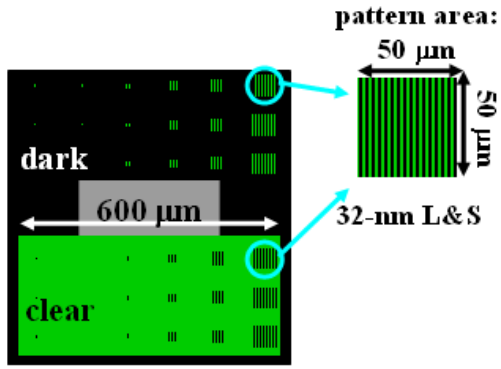
H. Aoyama *et al.*, Jpn. J. Appl. Phys., **48** (2009) 056510.

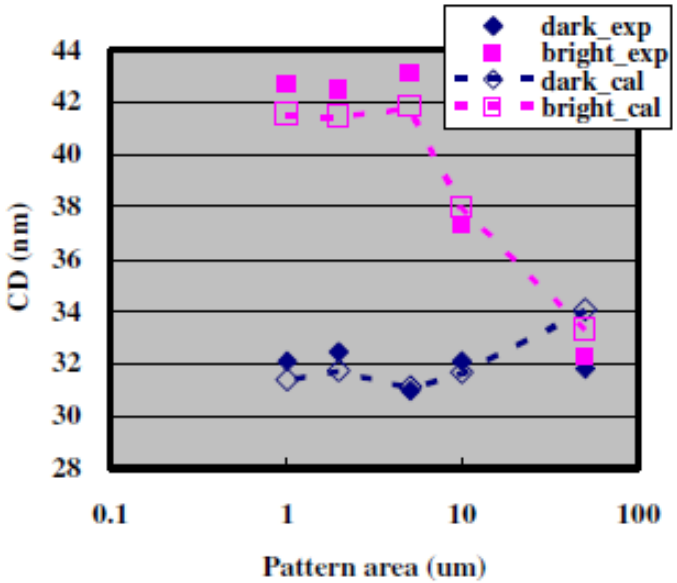
on dark area



on clear area







CD variation with flare can be precisely predicted using flare PSF and TIS.

calculation also including mask CD and resist blur effect

EUV1 PO #1 flare evaluation

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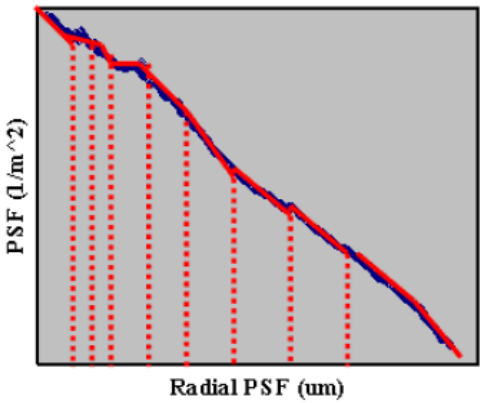
- FVC evaluation on PL test site

By courtesy of Selete/Toshiba

H. Aoyama *et al.*, Proc. SPIE **7271** (2009) 72712D.

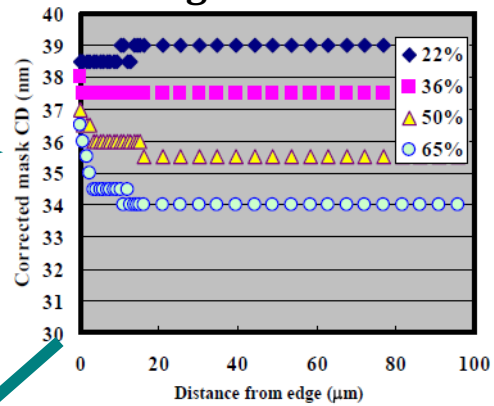
Raw PSF and multi-fractal function



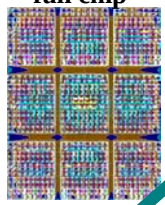
$$PSF(r) \approx \frac{c_1}{r^{n_1}} \quad (a_0 \le r < a_1)$$
$$+\frac{c_2}{r^{n_2}} \quad (a_1 \le r < a_2)$$
$$\cdots$$
$$+\frac{c_m}{r^{n_m}} \quad (a_{m-1} \le r < a_m)$$

flare mapping & mask resizing with EDA

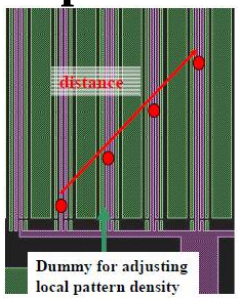
Mask target size with FVC



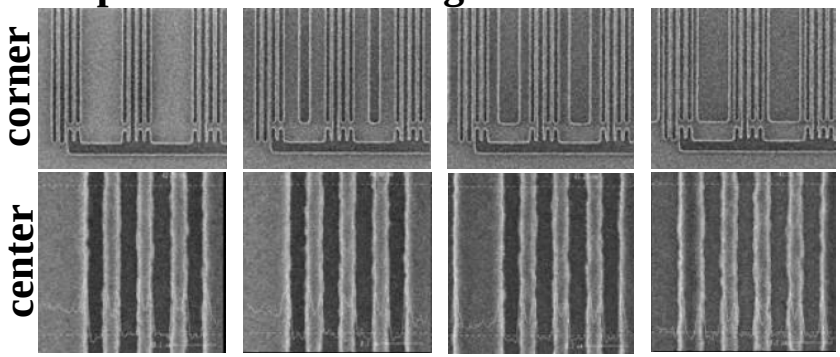
full chip



hp 35nm

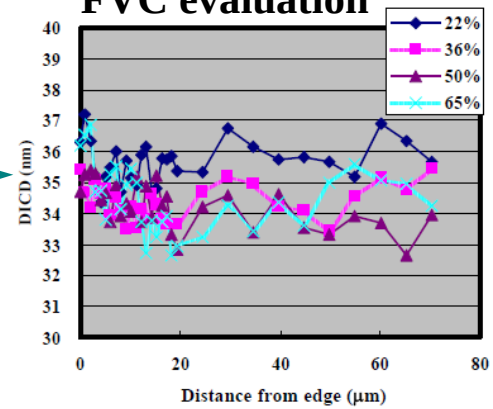


Top view of SEM images



Pattern density: 22% 36% 50% 65%

FVC evaluation



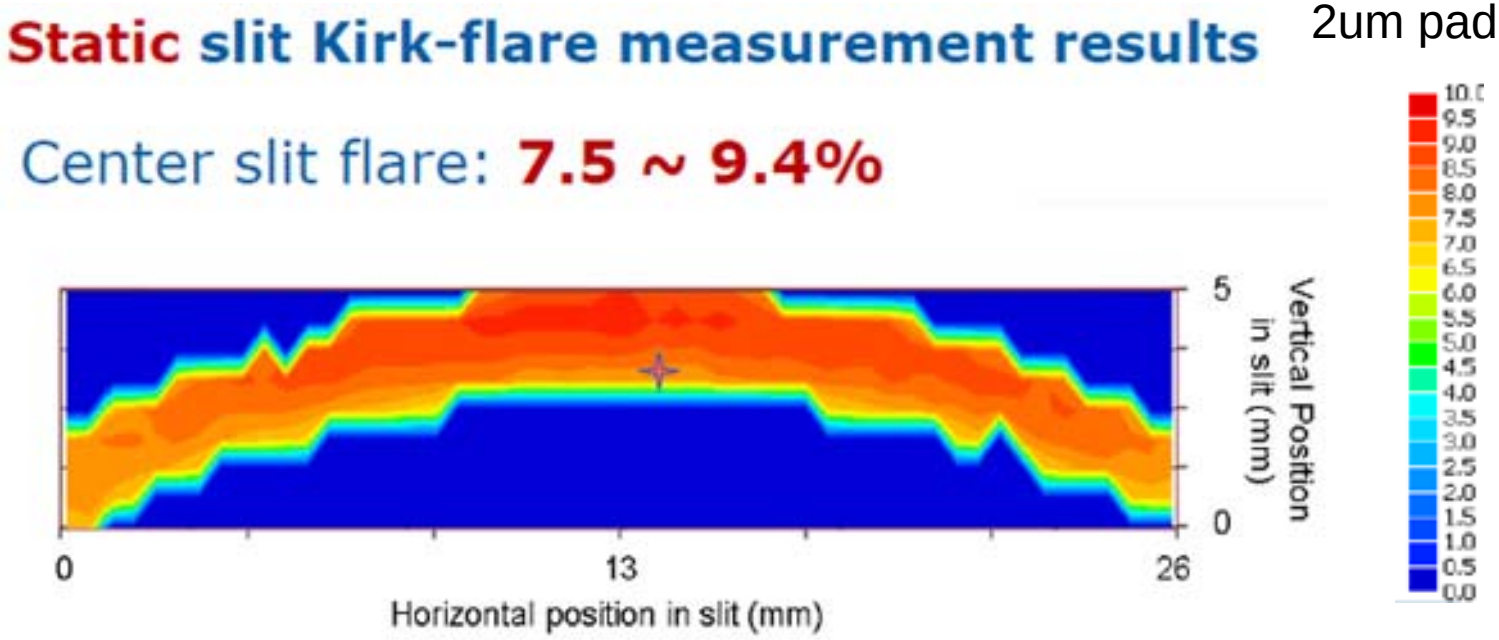
Flare variation compensation (FVC) based on flare PSF and TIS has +/– 2nm CD error in the range of 22%~65% pattern density.

EUV1 PO #2 flare evaluation

- Kirk-flare measurement

By courtesy of Intel

2um pad in bright field



This variation includes mask contrast variation of ~1% and the illumination non-uniformity.

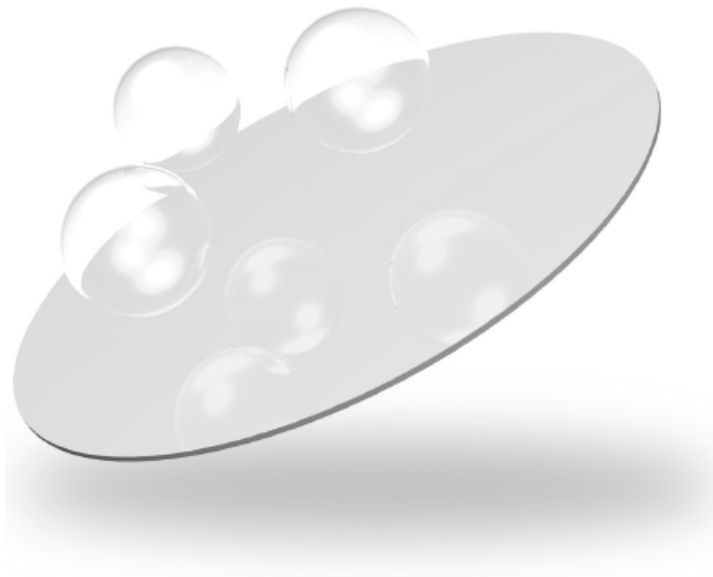
Calculated Kirk-flare value is 7.4% at the center of field.

*Additional details are on Intel's poster presented by **Yashesh Shroff** on EUV1 static imaging. ("Static Test Evaluation of EUV1 Full-Field Exposure Tools")

Summary

- New calculation method of flare PSF and TIS is developed.
- Using flare PSF and TIS obtained by our new method, actual flare behavior can be well predicted.
- Parameters characteristic of PO are flare PSF and TIS, which should be separately provided.
(TIS should not be obtained by integrating provided PSF.)

- Acknowledgements

- ***H. Aoyama, K. Tawarayama, Y. Tanaka and I. Mori* (*Selete*),** *providing precious flare evaluation data on Kirk-flare tests and on PL test site evaluation.*
- ***Y. Nakajima and R. Inanami* (*Toshiba*),** *PL test site design and evaluation.*
- ***A. Myers, Y. Shroff* (*Intel*),** *providing precious flare evaluation data.*
- ***M. Nakajima* (*Nikon*),** *throwing billions of scatter rays for months.*

Thank you.