An innovative method to retain optical kernels by keeping Bossung curves smoothness

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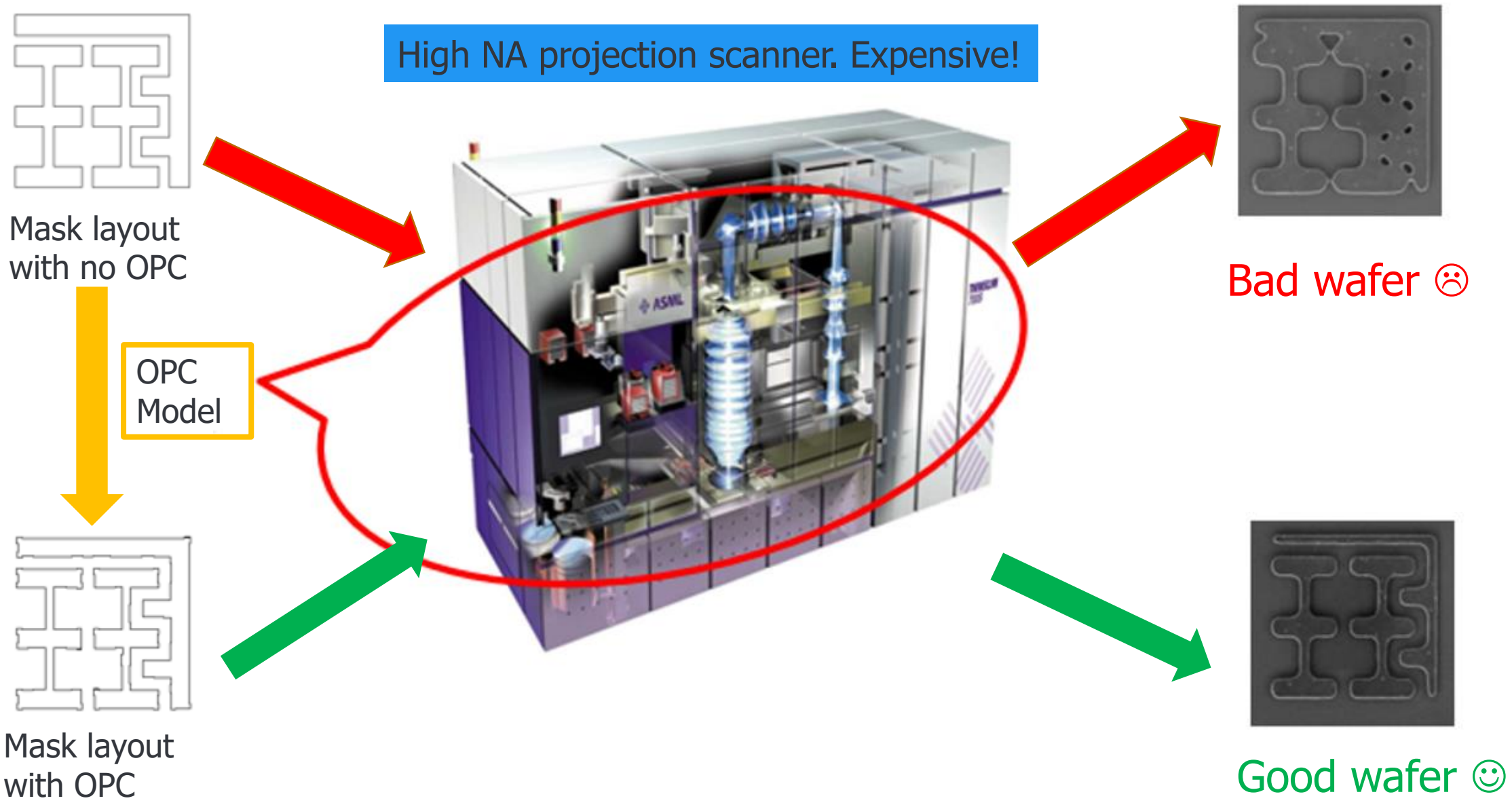
- Introduction to OPC modeling
- Optical imaging and Hopkins equation
- Bossung Curves in litho process
- Experimental setup and test patterns
- Conclusions

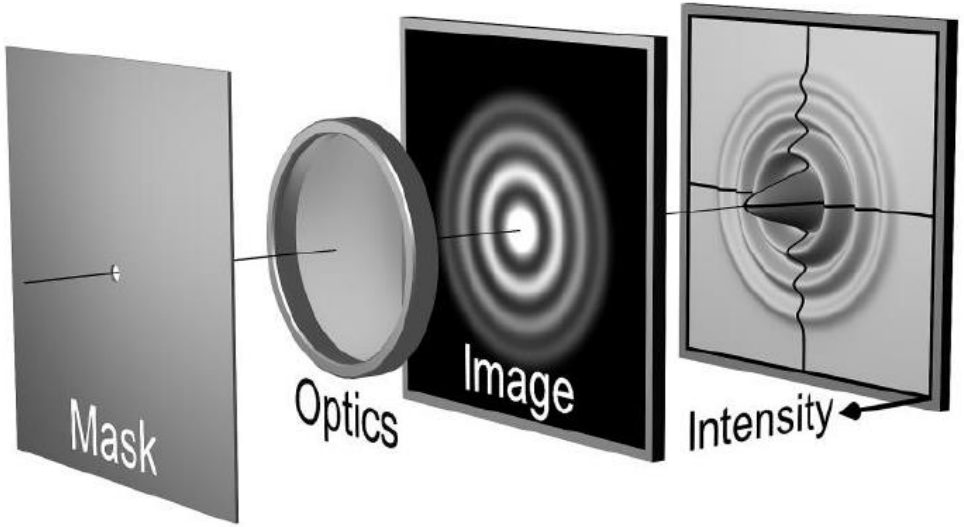
Introduction to OPC modeling

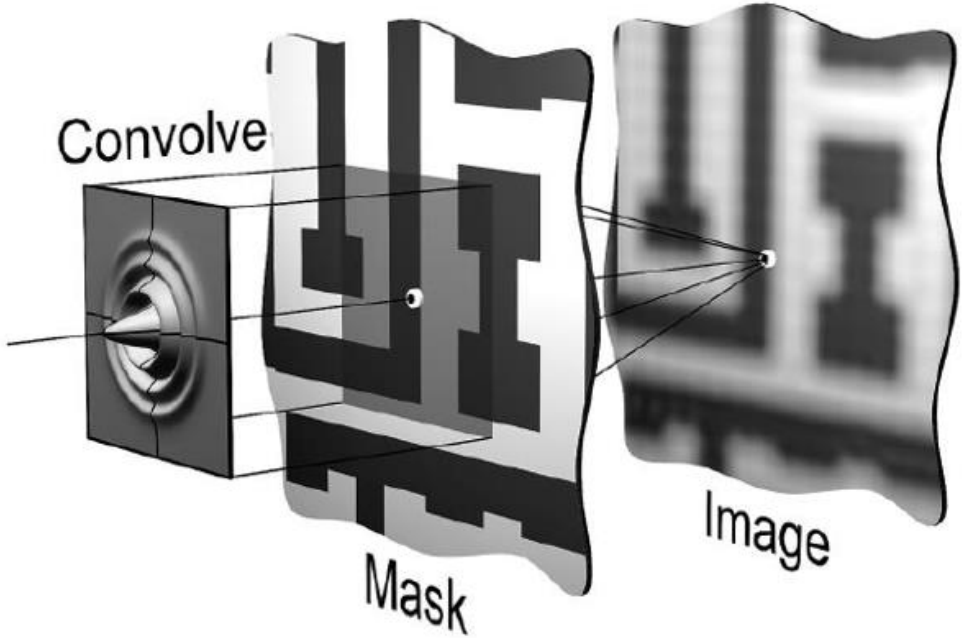


OPC model builds virtual fab

- A well calibrated OPC model can predict wafer behavior precisely for any given input layout.
- A well calibrated OPC model can predict wafer behavior through focus and through dose.
- A well calibrated OPC model can replace the very expensive scanner and act as a virtual fab.
- With virtual fab, one can correct any polygons on a layout at **very low cost!**
- Optical model builds the foundation for OPC model and controls its through focus/dose behavior. We will focus on optical model in the following discussion.

Optical imaging and mask convolution





Courtesy of Progen manual

The intensity profile of an imaged pinhole describes the imaging characteristics of a linear optical system, and can be used as a convolution kernel to model the system's characteristics.

The convolution value by convolving the intensity profile with an input pattern centered on a position (x, y) is the intensity of the output image at a corresponding point(x, y).

Hopkins equation for compact OPC model

- Hopkins Equation allows the wafer intensity to be calculated for any point in the input pattern.
- Based on the Hopkins equation, the aerial image intensity can be expressed as:

$$I(x,y) = \iint \iint M(x_1,y_1)T(x-x_1,y-y_1;x-x_2,y-y_2)M^*(x_2,y_2)dx_1\,dx_2dy_1dy_2$$

INTENSITY AT WAFER — MASK — TCC — complex conjugate of MASK

- *T(x-x1,y-y1;x-x2,y-y2)* is so called transmission cross coefficient (Tcc) function, which is given by

$$T(x-x_1,y-y_1;x-x_2,y-y_2) = J_0(x_1-x_2,y_1-y_2)P(x_1,y_1)P^*(x_2,y_2)$$

J0 represents the source of the illumination system

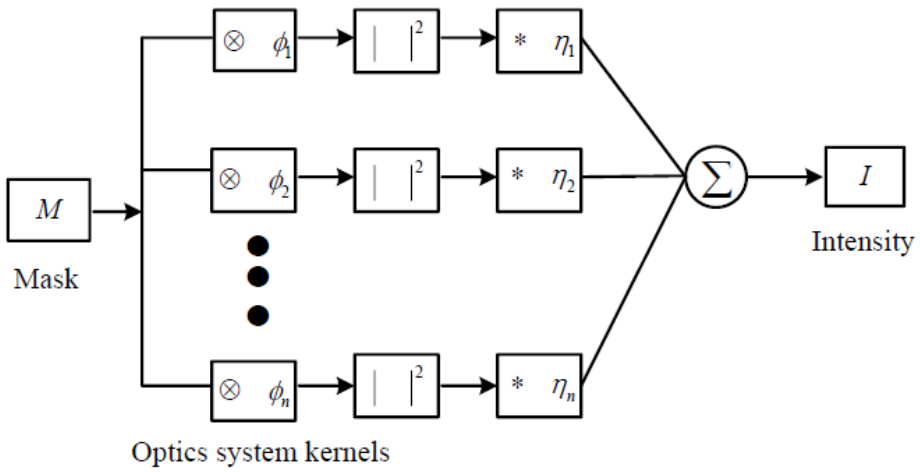
P and *P** represent the pupil of the projection system

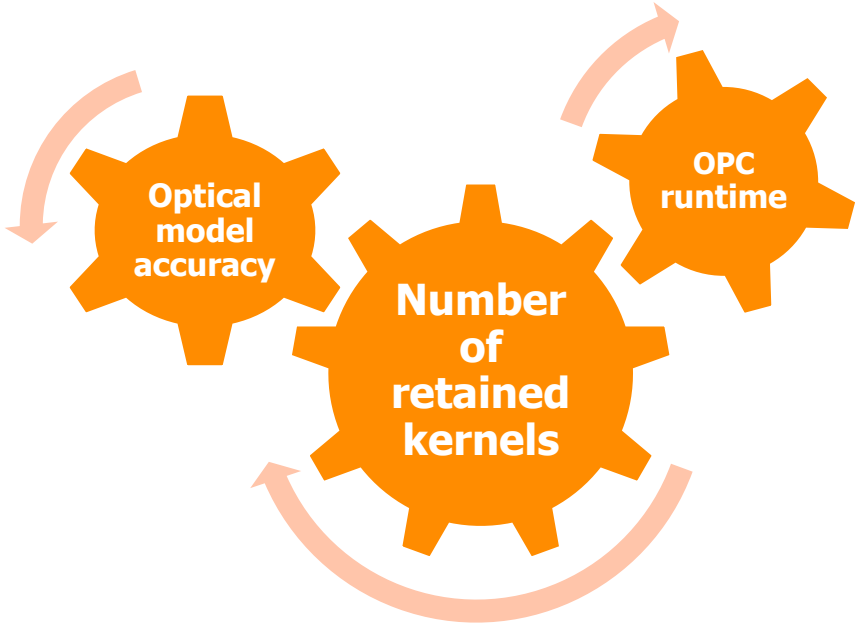
TCC decomposition into optical kernels

- TCC describes the action of the entire optical system from source to aerial image and it can be decomposed into a series of its eigen vectors

$$T(x_1, y_1; x_2, y_2) = \sum_{i=1}^{\infty} \lambda_i K_i(x_1, y_1) K_i^*(x_2, y_2)$$

$$I(x, y) = \sum_{i=1}^{\infty} \lambda_i \left| \int M(x_1, y_1) K_i(x - x_1, y - y_1)\, dx_1 dy_1 \right|^2$$





Truncation of TCC

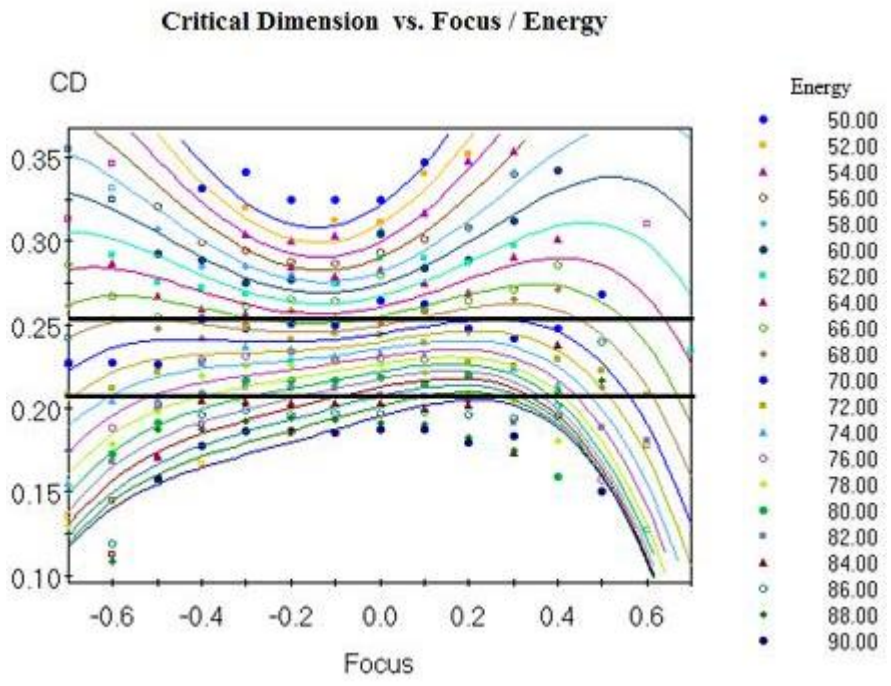
- To get compact OPC model, TCC must be truncated and only a finite number of kernels can be retained.

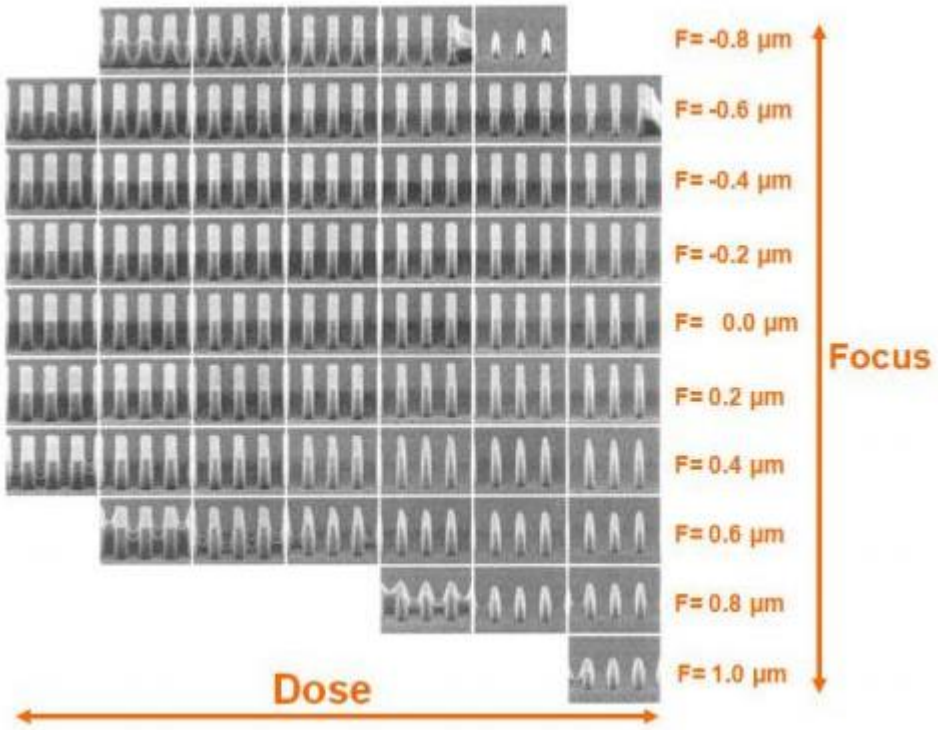
- When the optical system is defocused, TCC changes. Different TCCs under different focus may be truncated differently and, hence, impact through focus stability of optical model.

- **How to retain kernel such that the through focus behavior is smooth?**

Bossung Curves in litho process

Bossung curve maps a control surface for CD's as a function of the variables of focus and energy(dose).





Bossung curves are widely being used by litho engineers to find the common window in litho process.

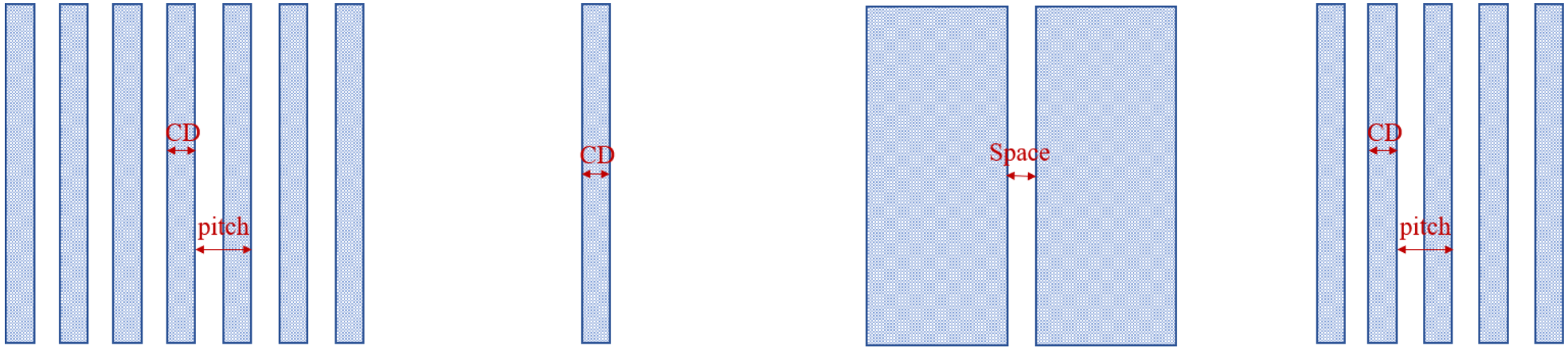
Bossung curve smoothness

In OPC modeling, we need to retain minimum and yet enough kernels to keep the smoothness of the Bossung curves

So we designed the following experiment

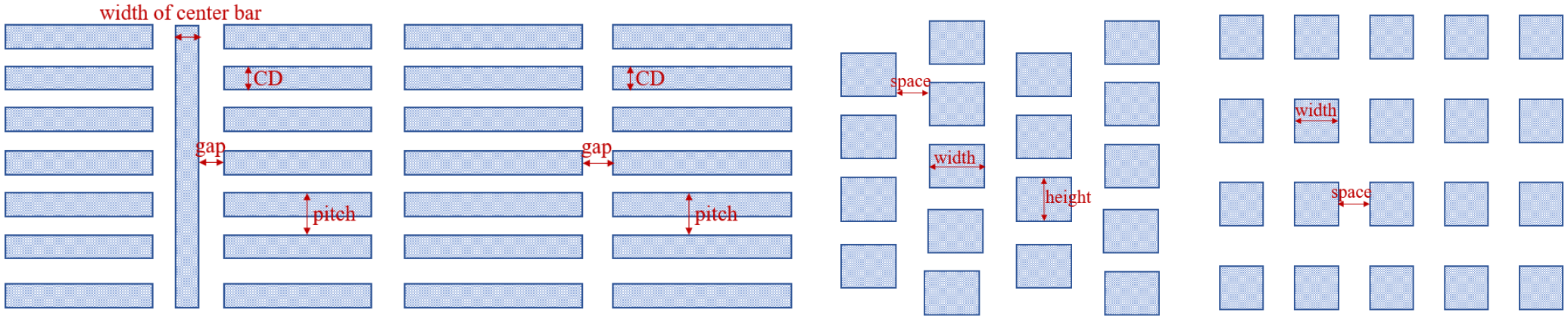
Test Patterns

1D



(1) dense line (2) isolated line (3) isolated space (4) 5-Bar

2D



(1) line-end (2) end-end (3) stagger (4) contact

Experimental settings

Different exposure conditions are studied through focus (from -45nm to 45nm with step of 5nm) at the best dose condition.

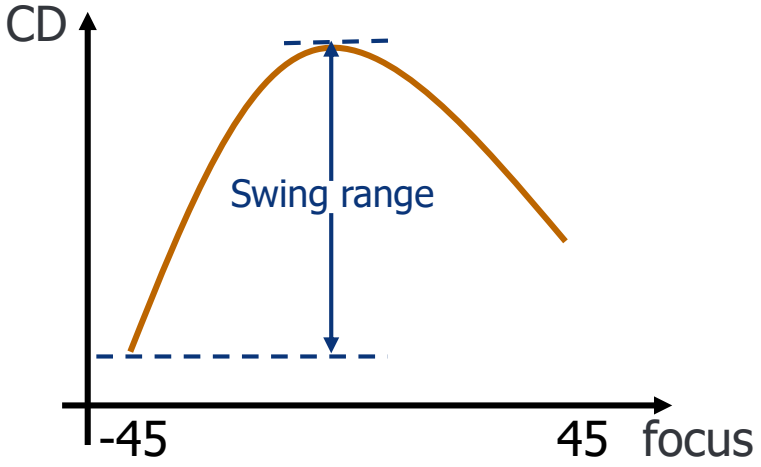
dose

1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
-45	-40	-35	-30	-25	-20	-15	-10	-5	0	5	10	15	20	25	30	35	40	45

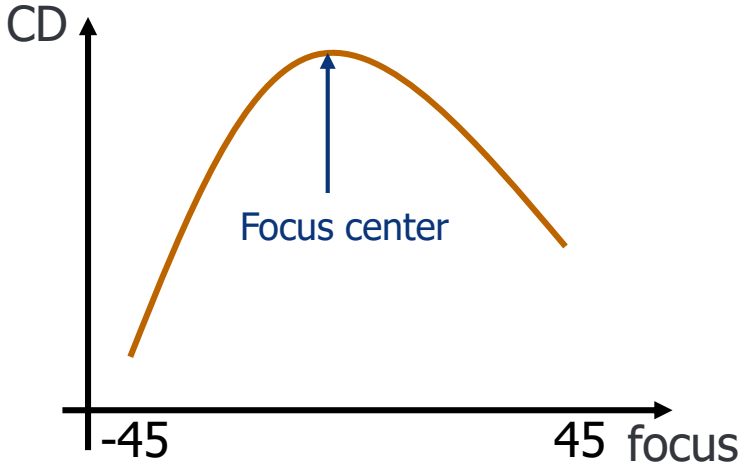
focus(nm)

To select the focus sensitive patterns for the study, two filters are applied:

(1) the swing range > 5nm



(2) the focus centre in +/- 45nm.

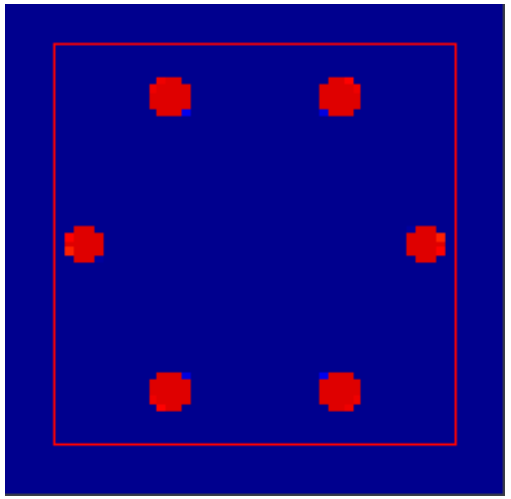


Experimental setup

A typical ArFi process is being selected for the experiment

Illumination source shape	Multipole
Source wavelength	ArF (193 nm)
Source polarization	sector
NA	1.35
Ambient refraction	1.43664 (immersion)
Mask background	clear field
Feature	Trans=0.063, phase=180
Mask magnification	4

Source

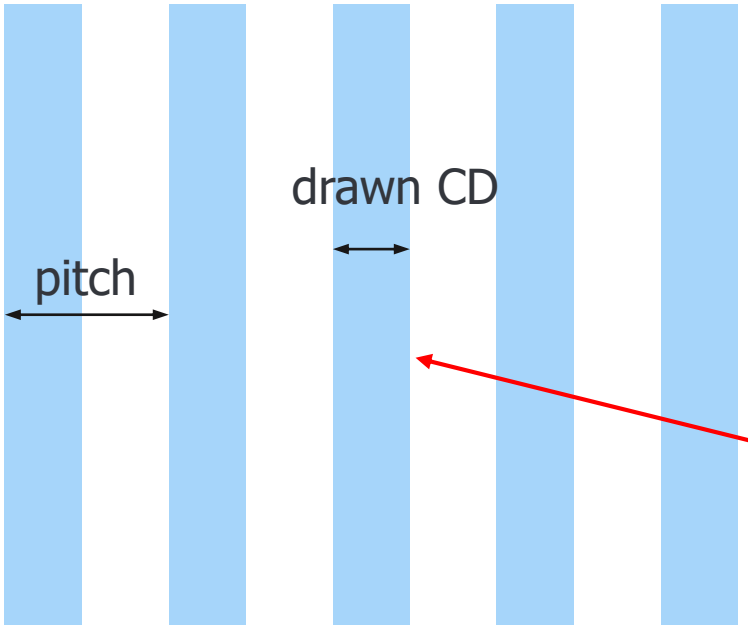


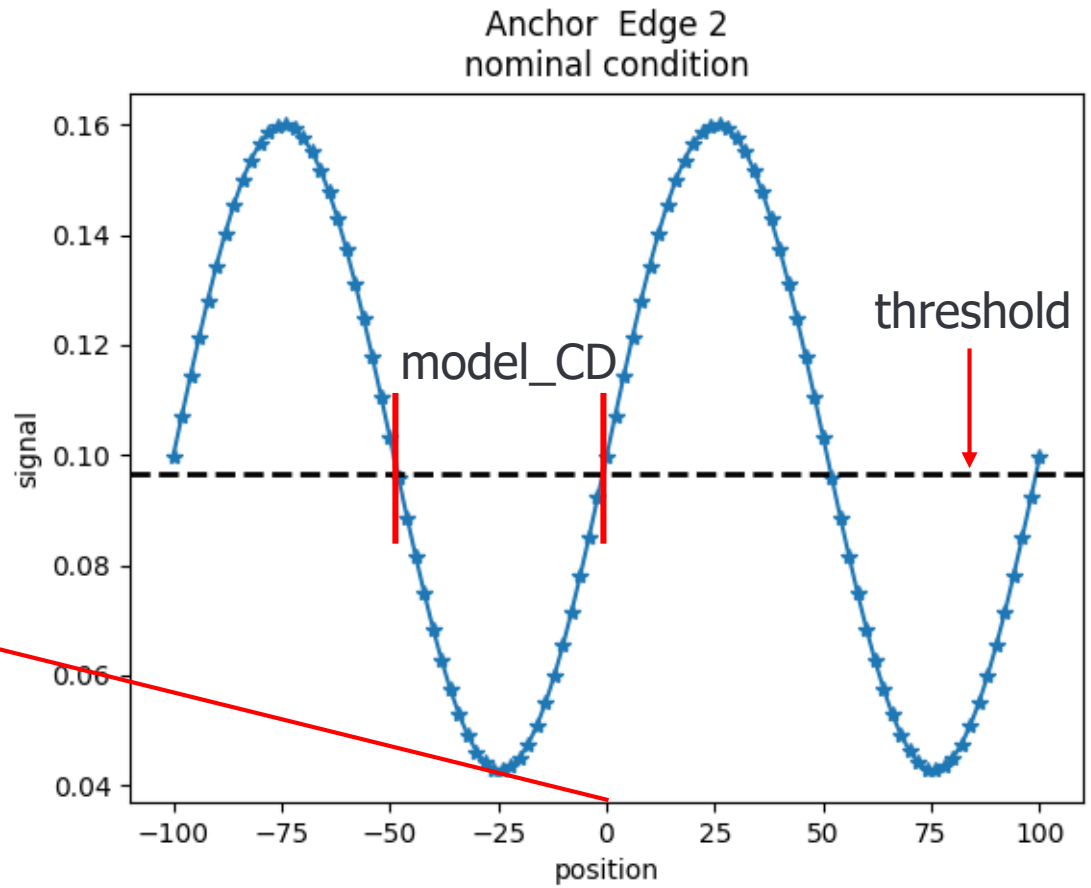
Source polarization is sector

Film stack is not shown to protect confidentiality.

Anchor and CD extraction

Anchor has drawn CD of 49nm and pitch of 100nm

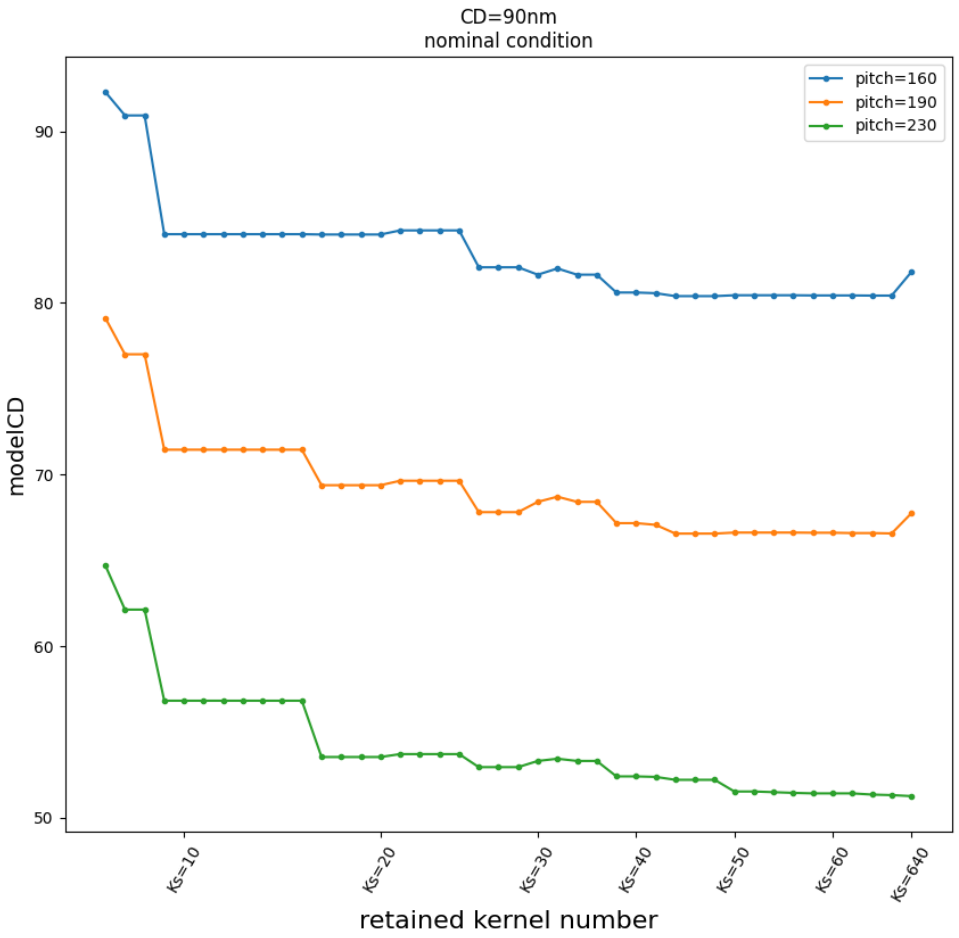




The threshold is computed by setting the anchor pattern on the drawn target of 49nm.

The intersections between the threshold and the optical signal determine the model CD for each gauge.

Model CDs vs retained kernels

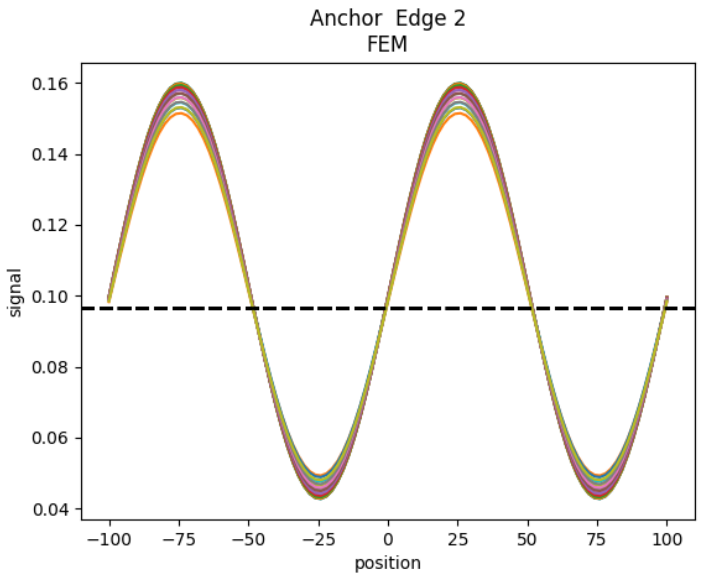


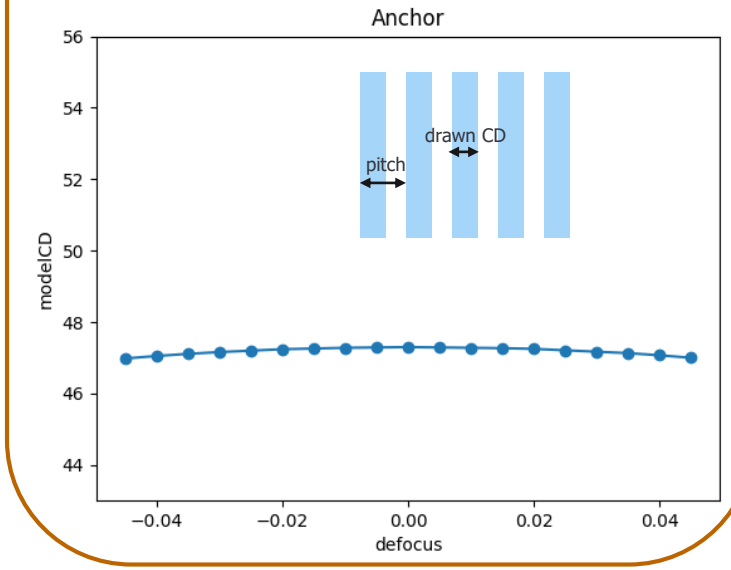
Threshold is locked by anchor pattern in each CD computation

Under nominal condition, strong dependency of model CD on retained kernels is observed

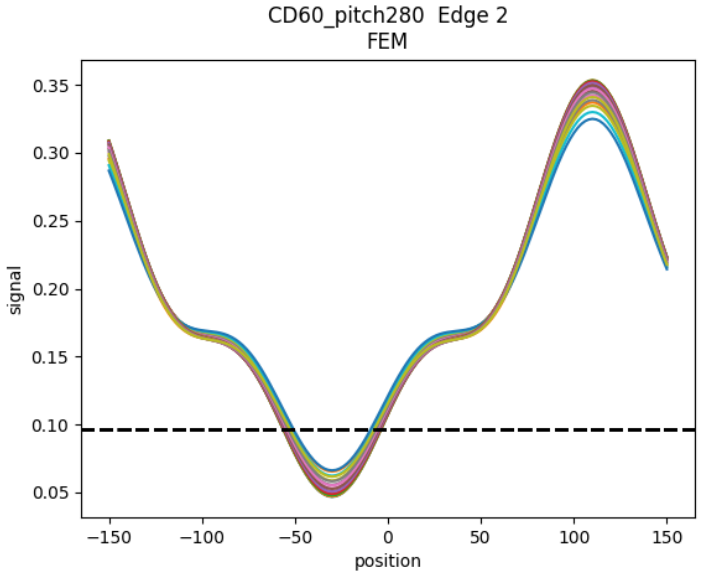
Through focus behavior of selected patterns

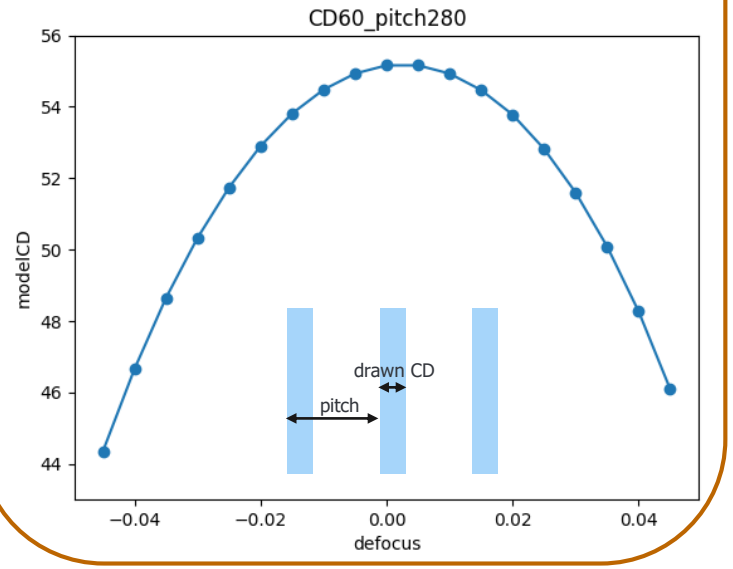
Anchor



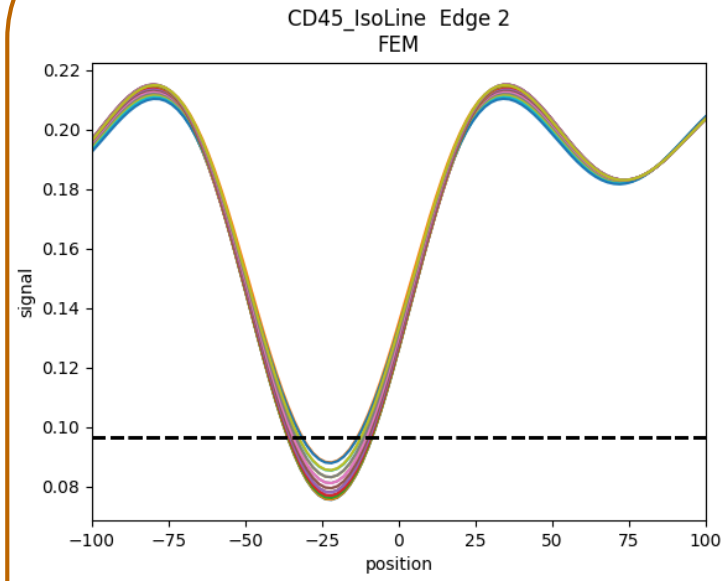


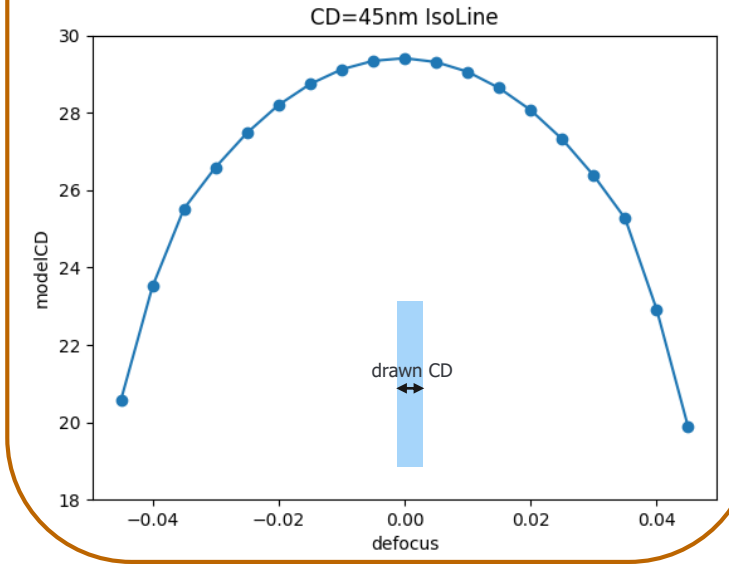
Semi Dense line



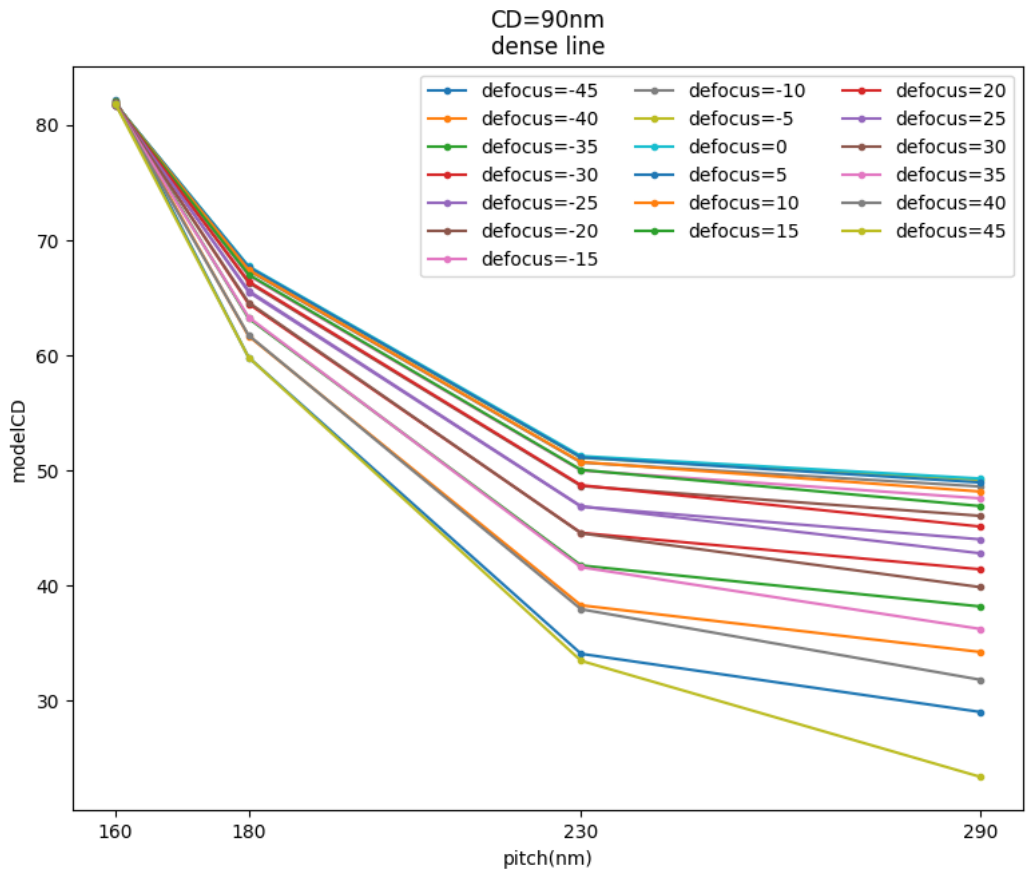


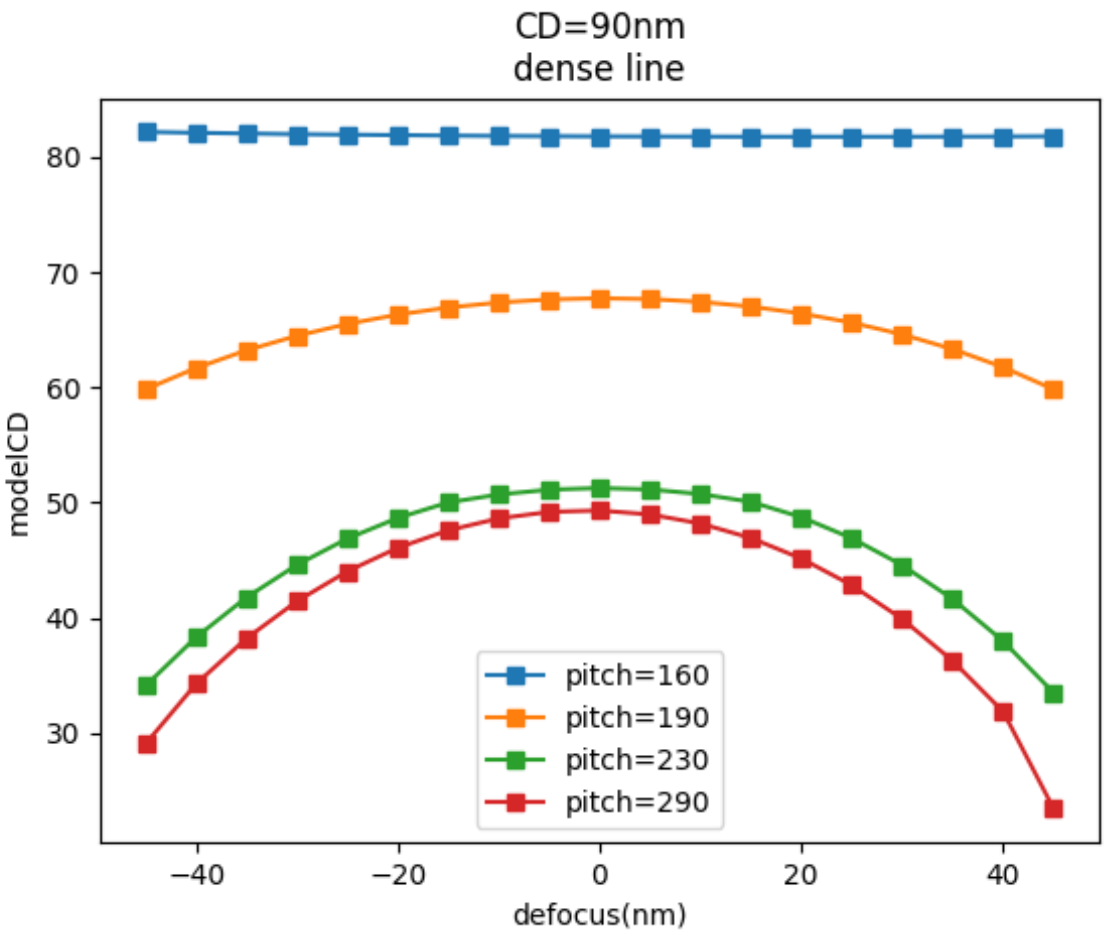
iso line





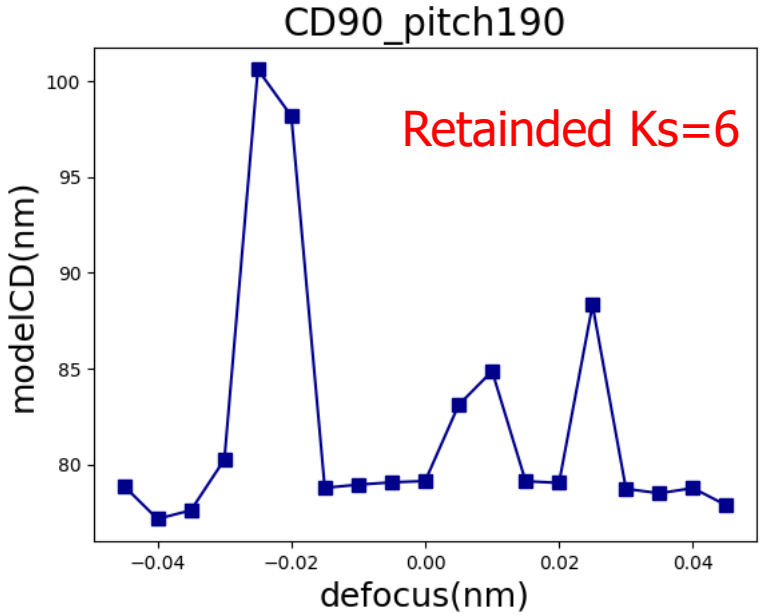
Bossung curves of through pitch patterns

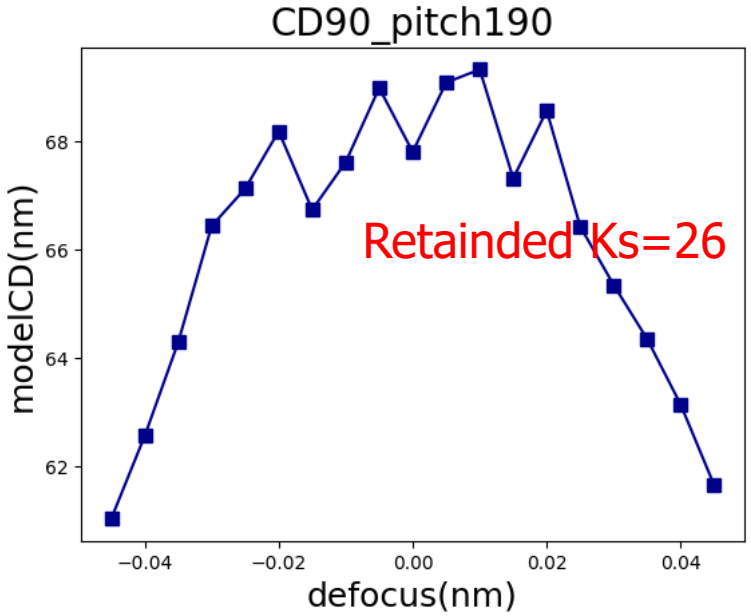


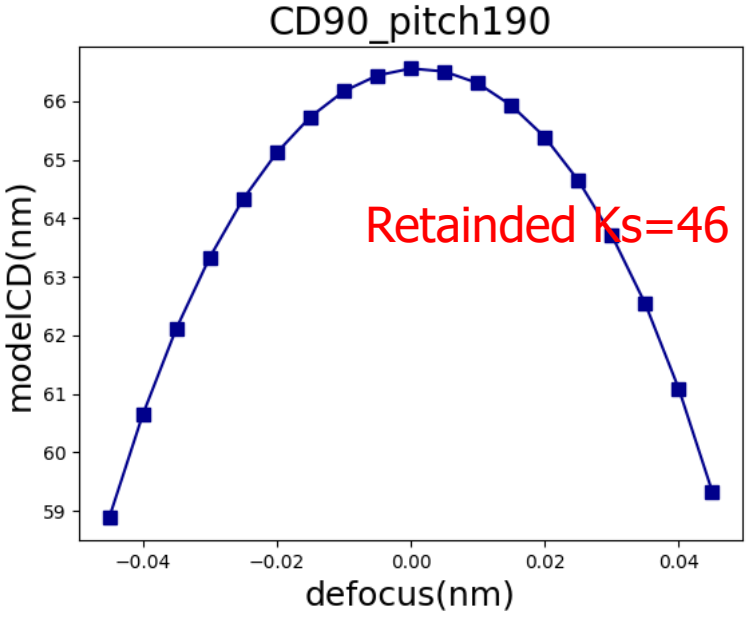


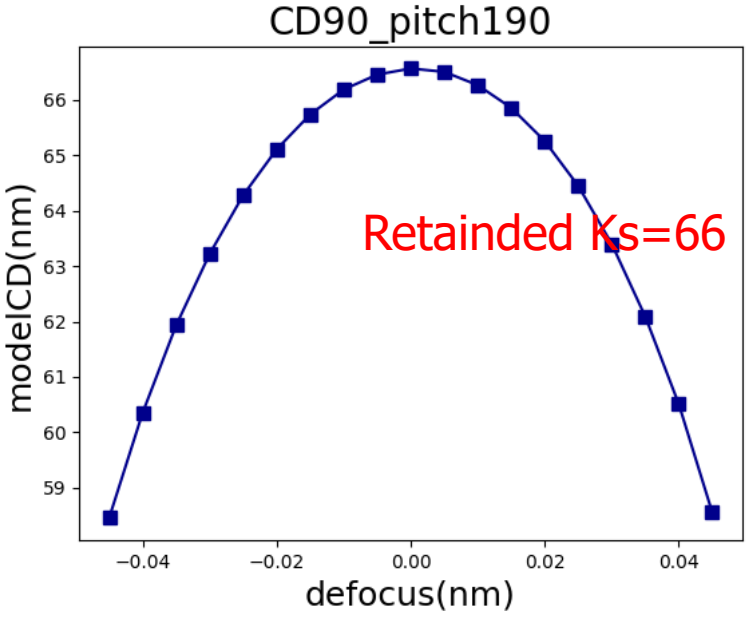
Retained Kernels = 640

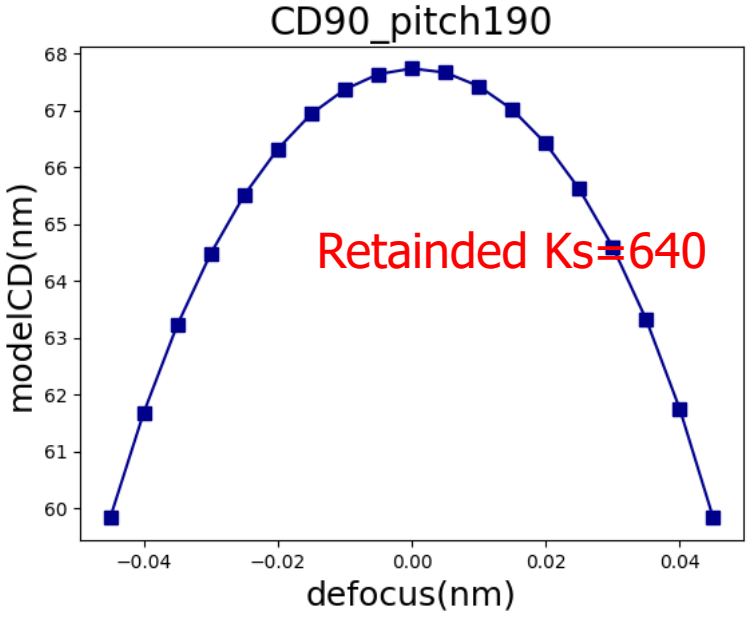
Bossung curves vs retained kernels



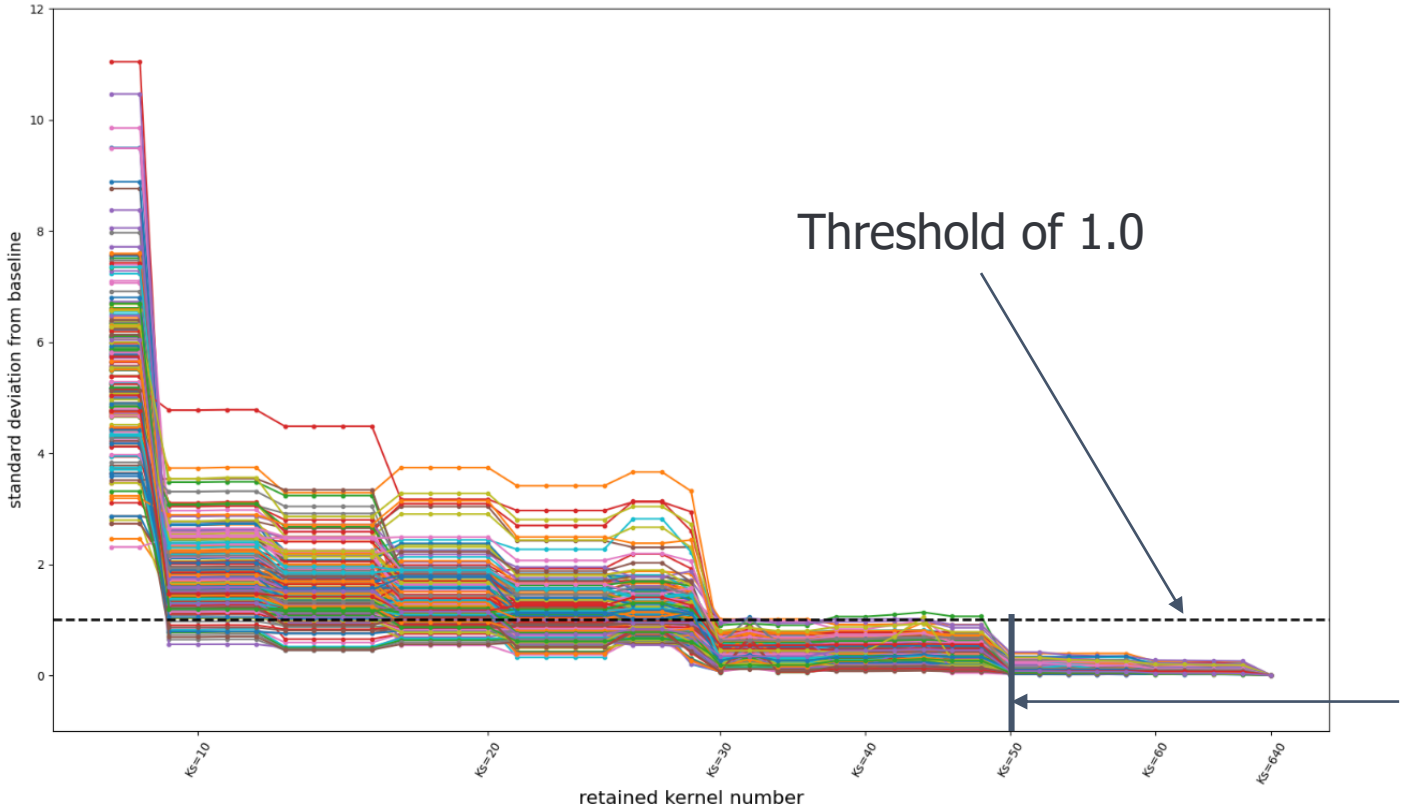








Simulation results



Minimum kernels needed to keep Bossung curve smoothness for all patterns

- Bossung curve with 640 retained kernels is considered the perfect base line
- The deviation of other retained kernels from 640 is computed and plotted
- Threshold of 1.0 is selected to pick the minimal number of retained kernels needed for all gauges
- Based on selected threshold, **50 kernels** are needed to keep the Bossung curve smoothness.

Conclusions

1. We discussed the need to maintain the through focus behavior of optical model
2. We checked CDs dependency on retained kernels under nominal condition
3. We checked CDs dependency on retained kernels through focus
4. We proposed a method to retain minimum and yet enough optical kernels such that the model can keep the Bossung curve smoothness

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Thank You!

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