Impact of lens aberration on CD and position for low k1 lithography

Xiaodong Meng
AMEDAC AE Group
2020-11-05

- Resolution Limitation
- Lens aberration
- Induced Effect and Analysis
- Summary and Discussion

Resolution Limitation

Low k1 lithography

$$R = k_1 \frac{\lambda}{NA}$$

38

193nm

1.35

0.25

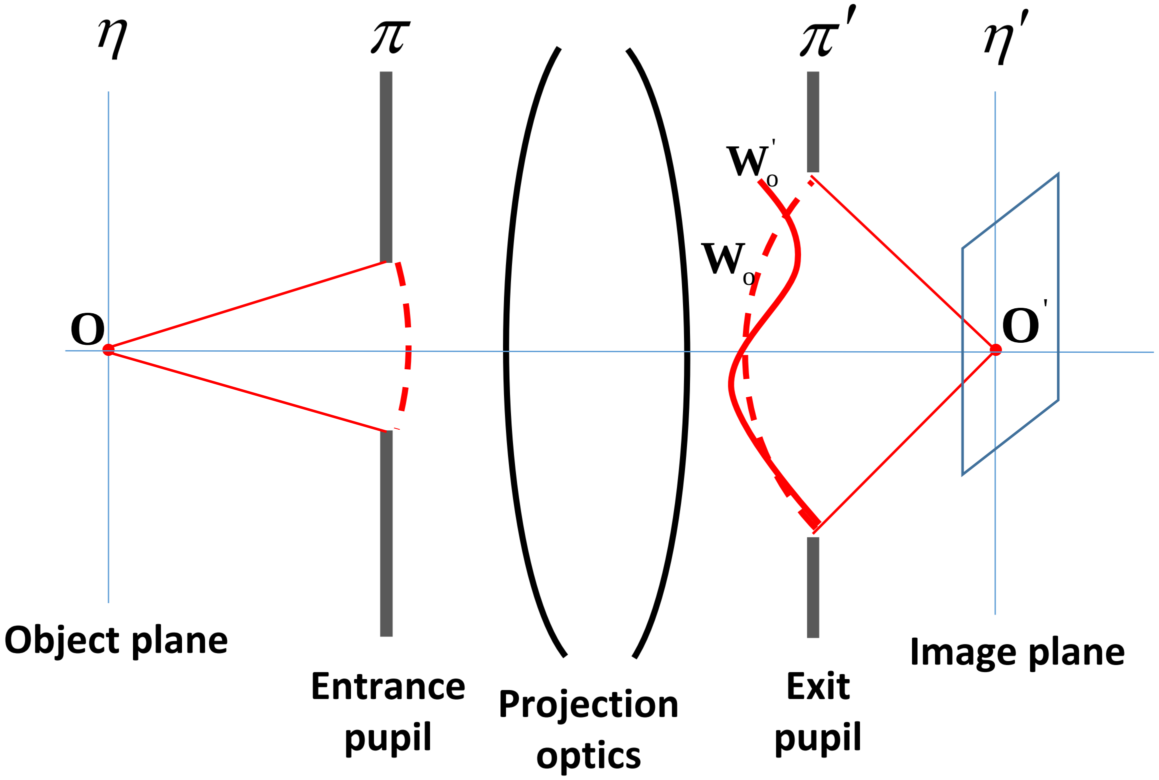
- The resolution is 38~40nm for immersion lithography, the k1 factor is close to the 0.25 limit.
- Even with strong RET, the resolution limitation (with Process Window) of single exposure is about Pitch 76nm (single direction).
- For precise lithography, any error may lead to resolution decline.
- Therefore, we need to concern any proximity including lens aberration.

全芯智造 AMEDAC

- Resolution Limitation
- Lens aberration
- Induced Effect and Analysis
- Summary and Discussion

Lenses aberration

To calculate Lens aberration effect



The Lens aberration represents the wavefront distortion on the exit pupil plane

Phase Error

Aberration-aware imaging model

How the aberration impact the lithography performance?

$$P'(f_x, f_y) = P(f_x, f_y)\exp(\mathrm{i}2\pi\mathbf{W})$$

Pupil function is modulated by lens aberration as phase errors.

After inverse Fourier transformation, we can get the optical lithography image from pupil fields.

Zernike Polynomials

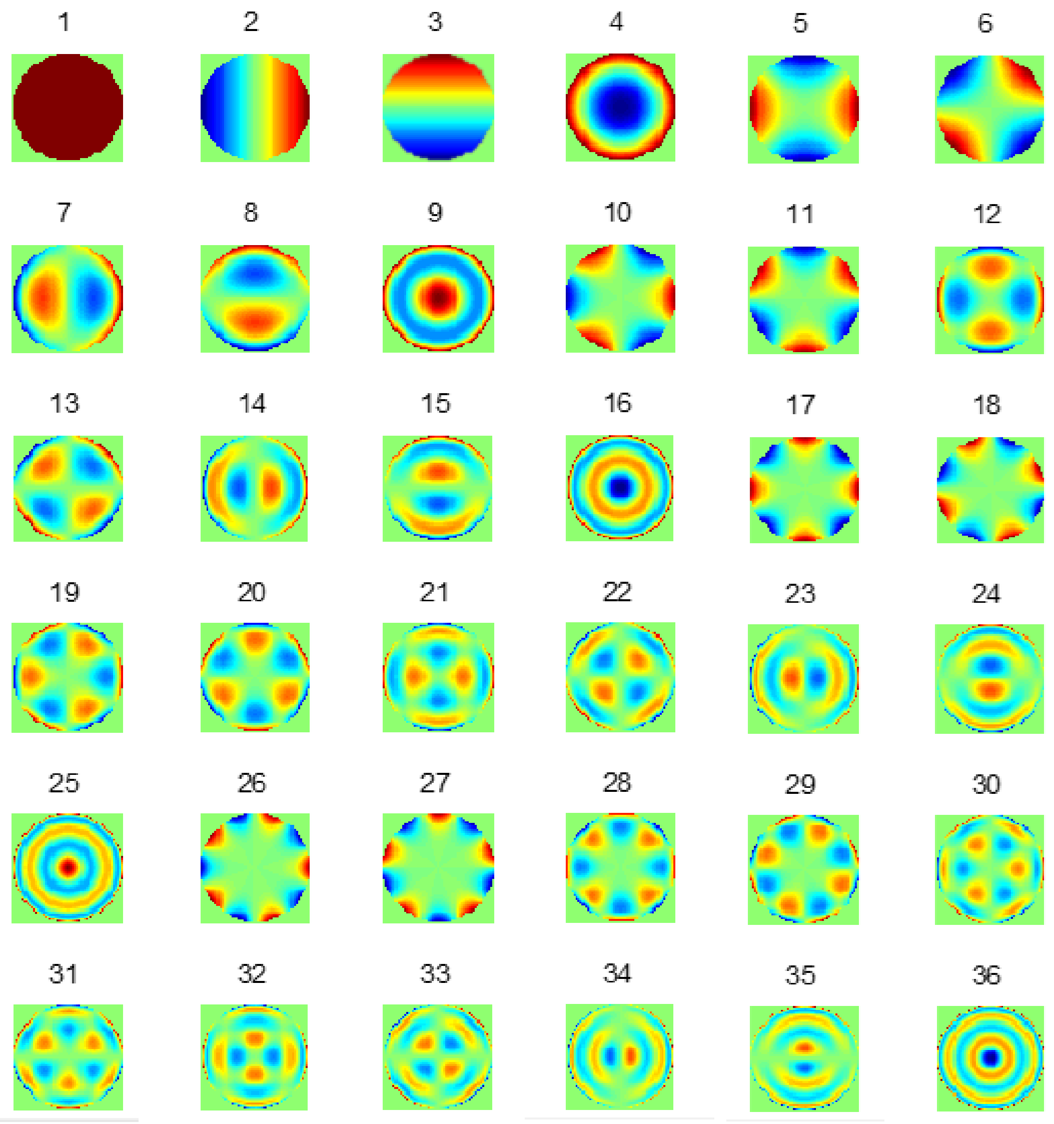
$$\mathbf{W} = \sum_{i} z_i \, \Gamma_i$$

Use Zernike series to represent aberration in circular pupil.

The first 36 Zernike Polynomials

Even aberration: 4, 9, 16, 25, 36, …

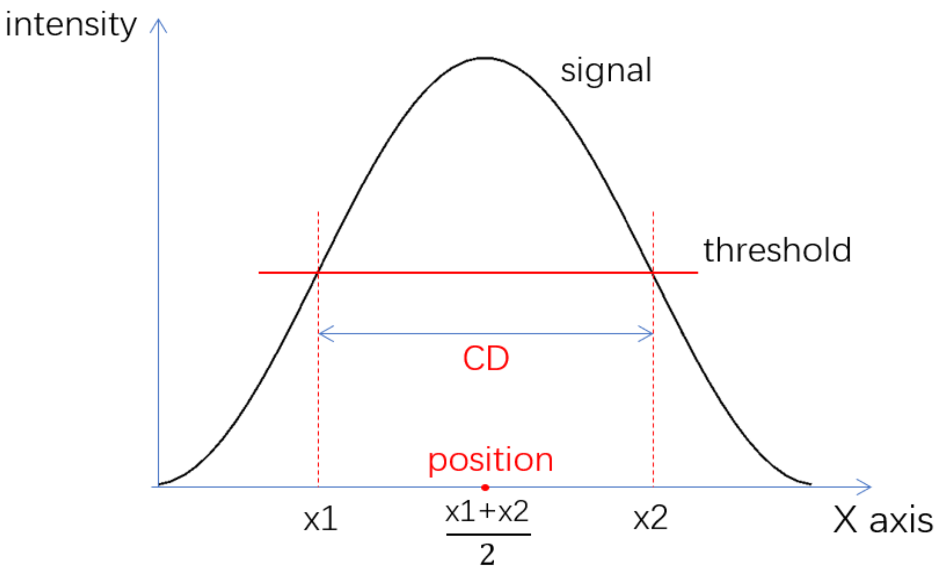
odd aberration: 2, 3, 5, 6, 7, 8, …



- Resolution Limitation
- Lens aberration
- Induced Effect and Analysis
- Summary and Discussion

Error Identification

ΔCD and Δposition

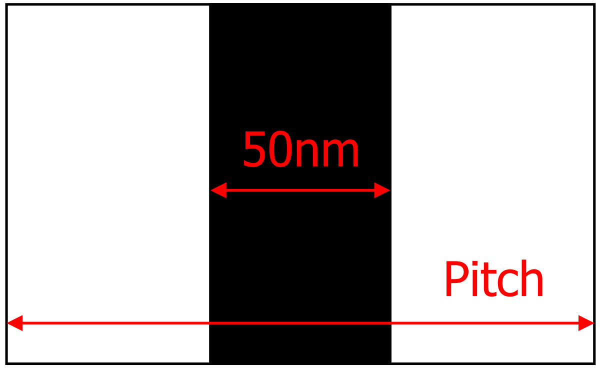


In order to study the impact of lens aberration with different configurations, we provide the ΔCD and Δposition with every single Zernike coefficient at 0.01λ.

Verified 1D pattern and setting

1D Pattern Configuration

Line-space pattern



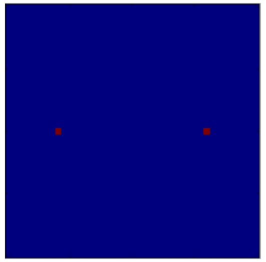
Reduction ratio 4:1

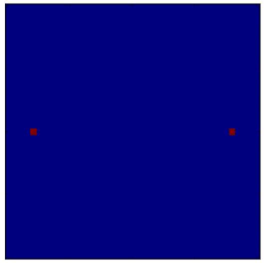
Wavelength 193nm

Illumination type:

x Dipole

TE-polarization


sigma 0.6


sigma 0.8

Wafer stack

80nm resist (n=1.69,k=0.05)

Substrate Si (n=0.883,k=2.778)

Optional parameter:

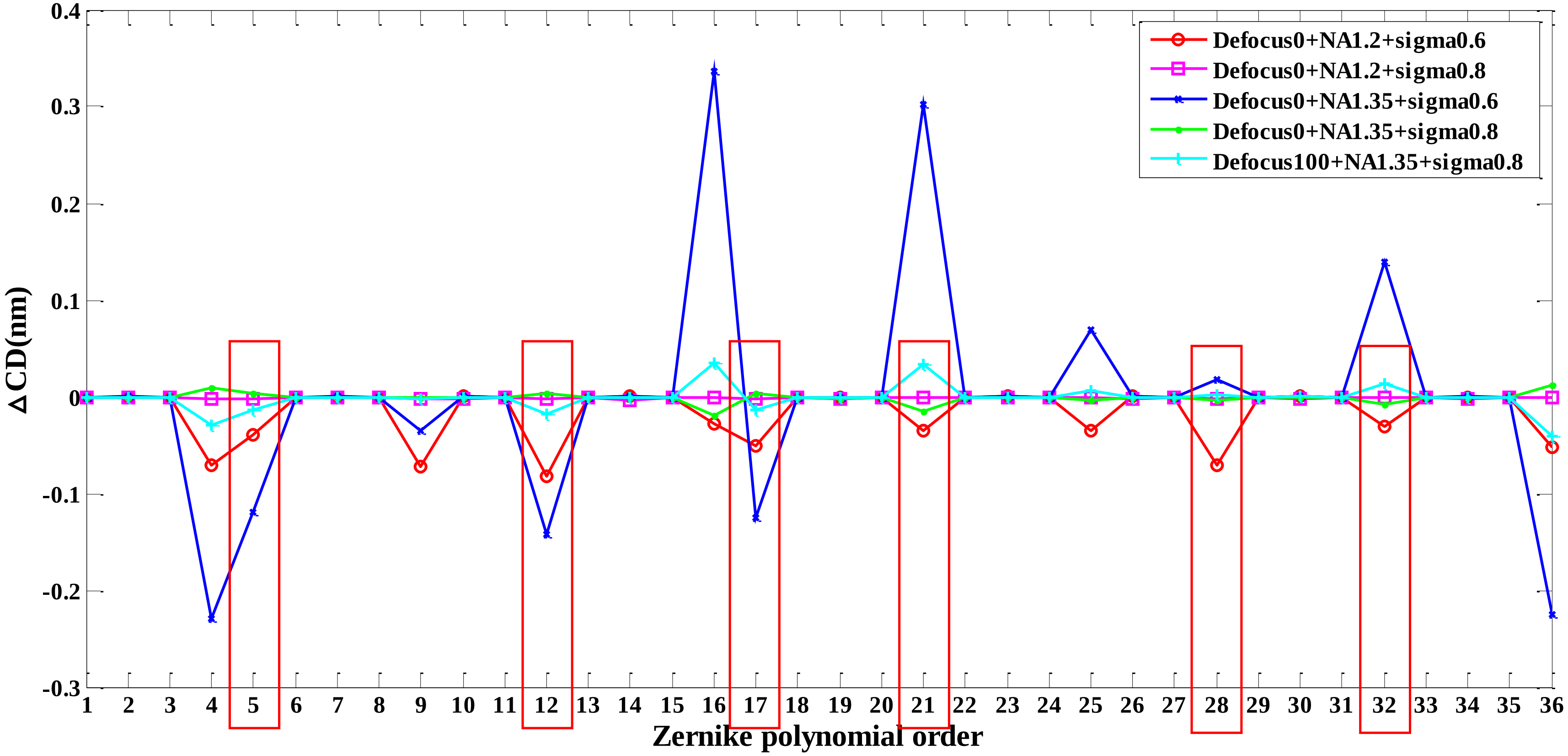
Pitch 100nm or 200nm illumination sigma 0.6 or 0.8

NA 1.2 or 1.35 defocus 0nm or 100nm

Result and discussion

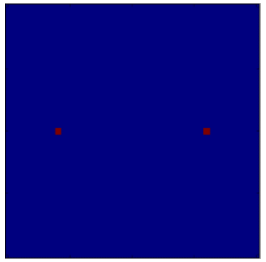
Pitch 100nm (dense line)

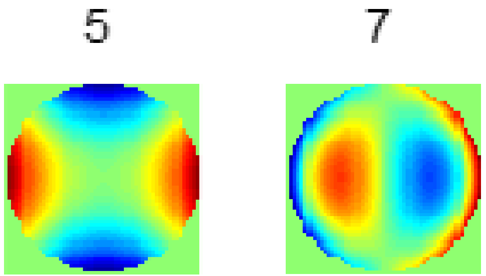
CD result



Except even aberrations, some odd aberrations also create CD variation

The 5, 12, 17, 21, 28, 32th Zernike polynomials will lead to delta CD

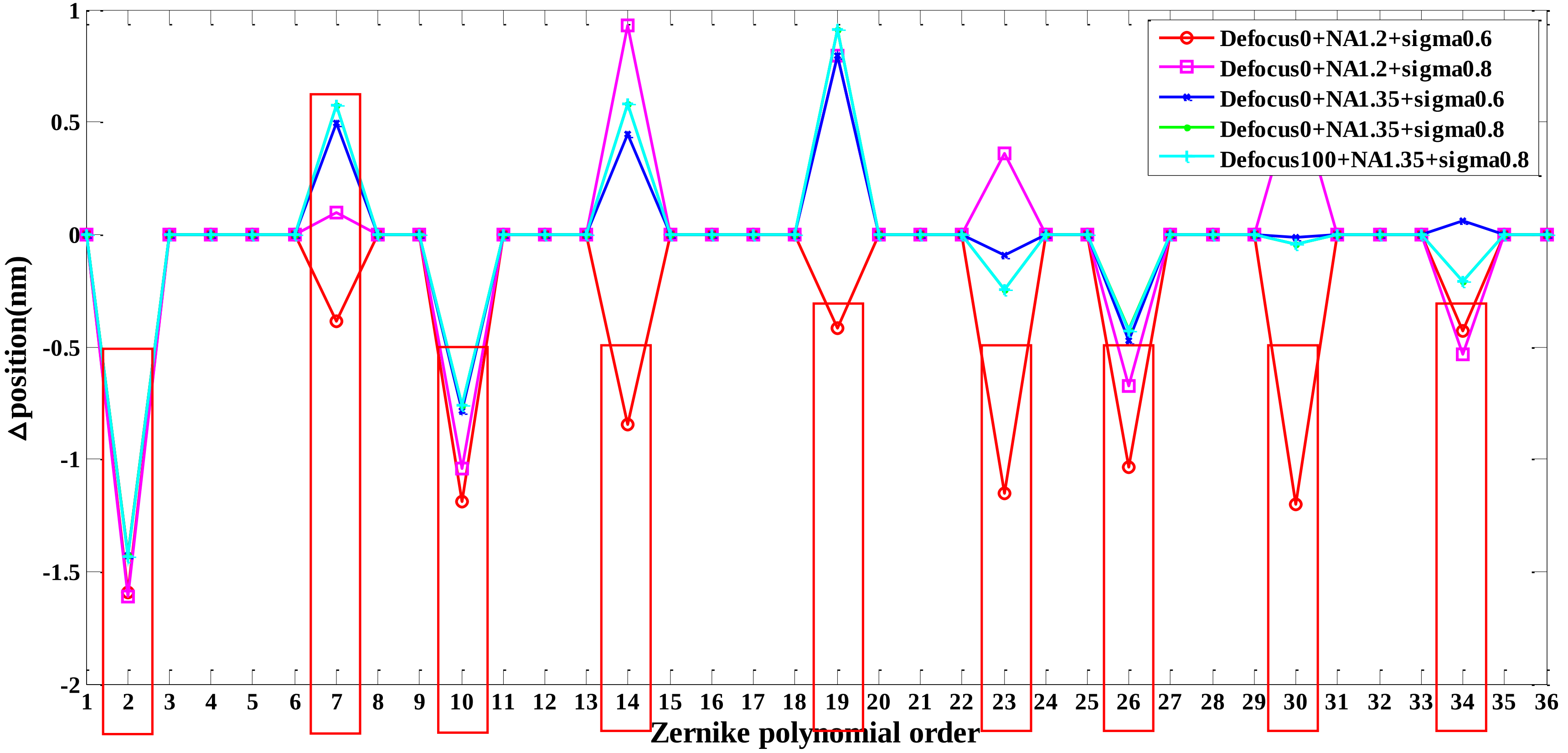




Result and discussion

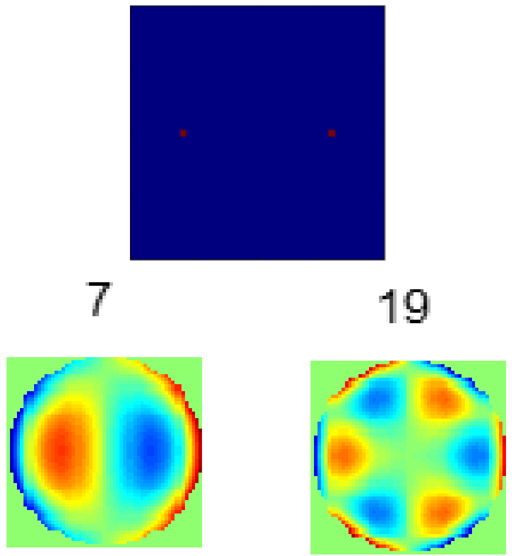
Pitch 100nm (dense line)

position result



Not all odd aberrations can create position shift.

The 2,7,10,14,19,23,26,30, 34th Zernike polynomials will lead to position shift.



Result and discussion

Pitch 100nm (dense line)

The impact of odd aberrations on optical imaging:

vertical line pattern + x dipole illumination → The diffraction order is only at x-axis.

Only the Zernike term with non-zero distribution at x-axis can impact optical imaging.

At x axis with symmetry, such as 5,12,17,21,28,32, it will create CD variation.

At x axis with anti-symmetry, such as 2,7,10,14,19,23,26,30,34, it will create position variation.

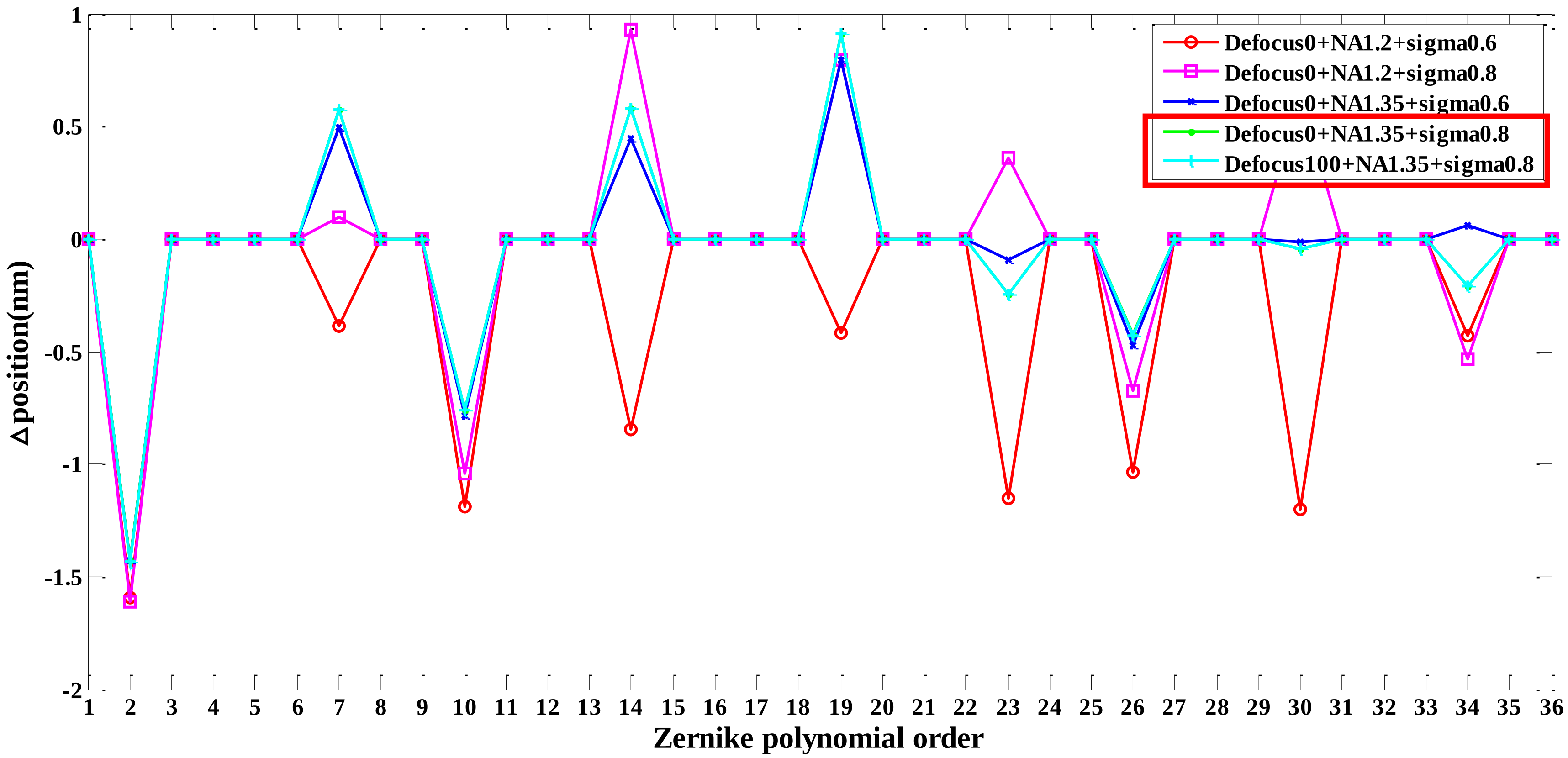
For 1D pattern, we can do rigorous analysis of diffraction order and predict every aberration term’ s impact on CD and position.

Result and discussion

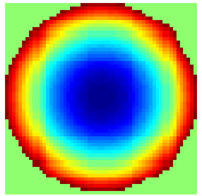
Pitch 100nm (dense line)

Defocus

The defocus equals a residual Z4, which does not cause Δposition variation.



4

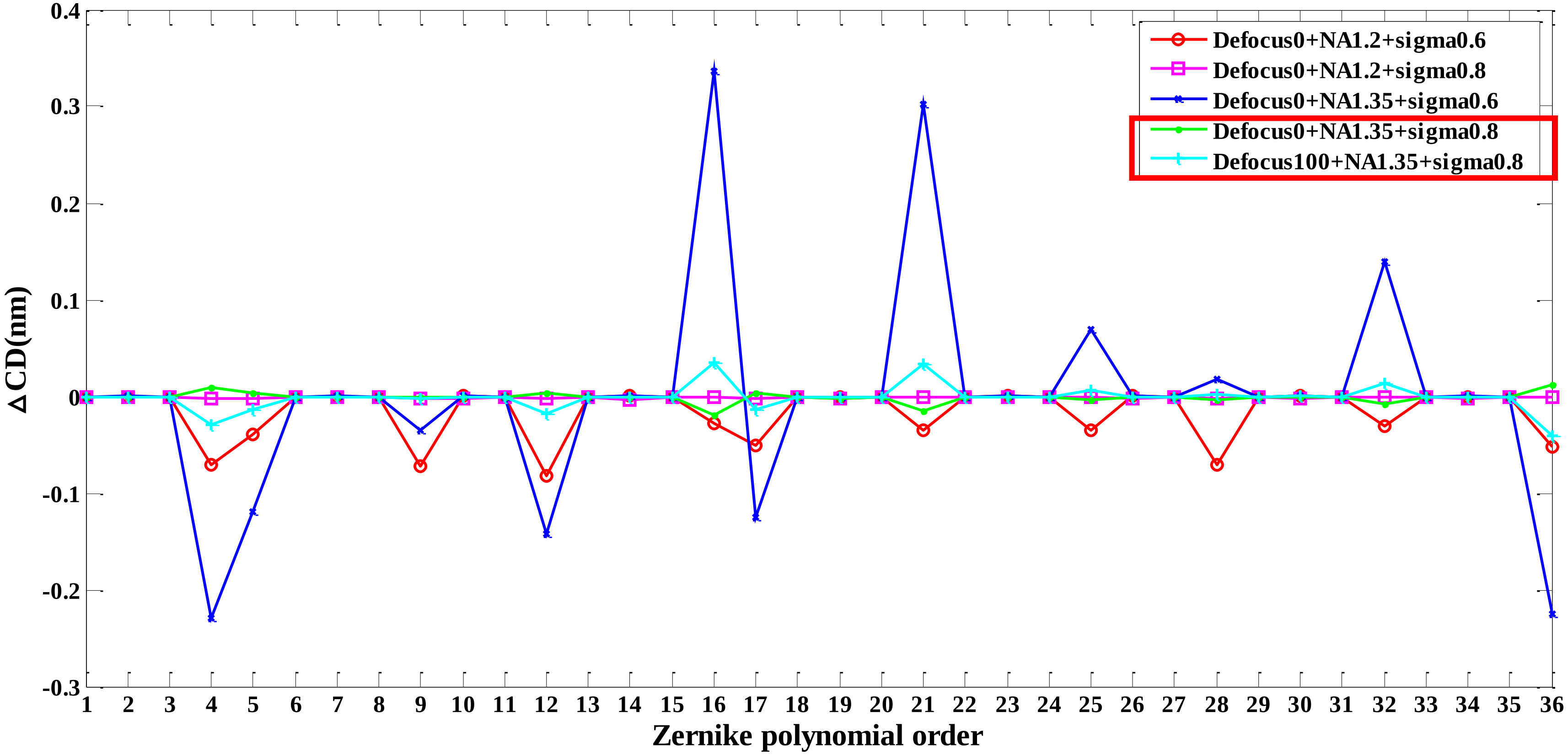


Result and discussion

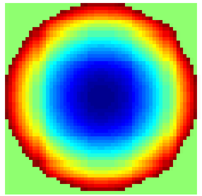
Pitch 100nm (dense line)

Defocus

But the defocus will create a little ΔCD variation due to the residual Z4.



4



Result and discussion

Pitch 100nm (dense line)

NA and sigma

Large NA will make the diffraction orders near to the center of circular pupil

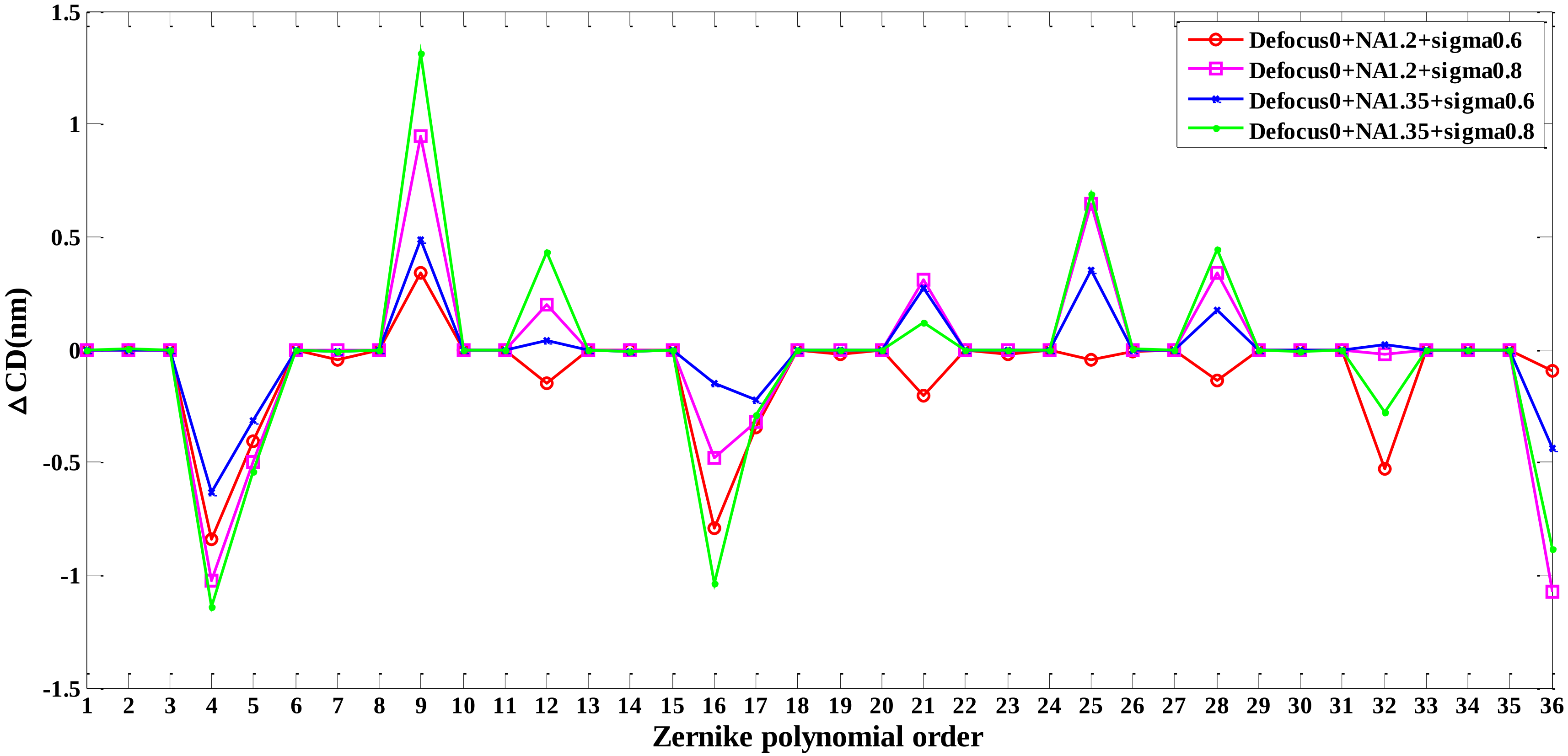
Large sigma will enlarge the shift of diffraction orders

So, the NA and sigma performance is dependent on Zernike polynomial distribution

Result and discussion

Pitch 200nm (semi-dense line)

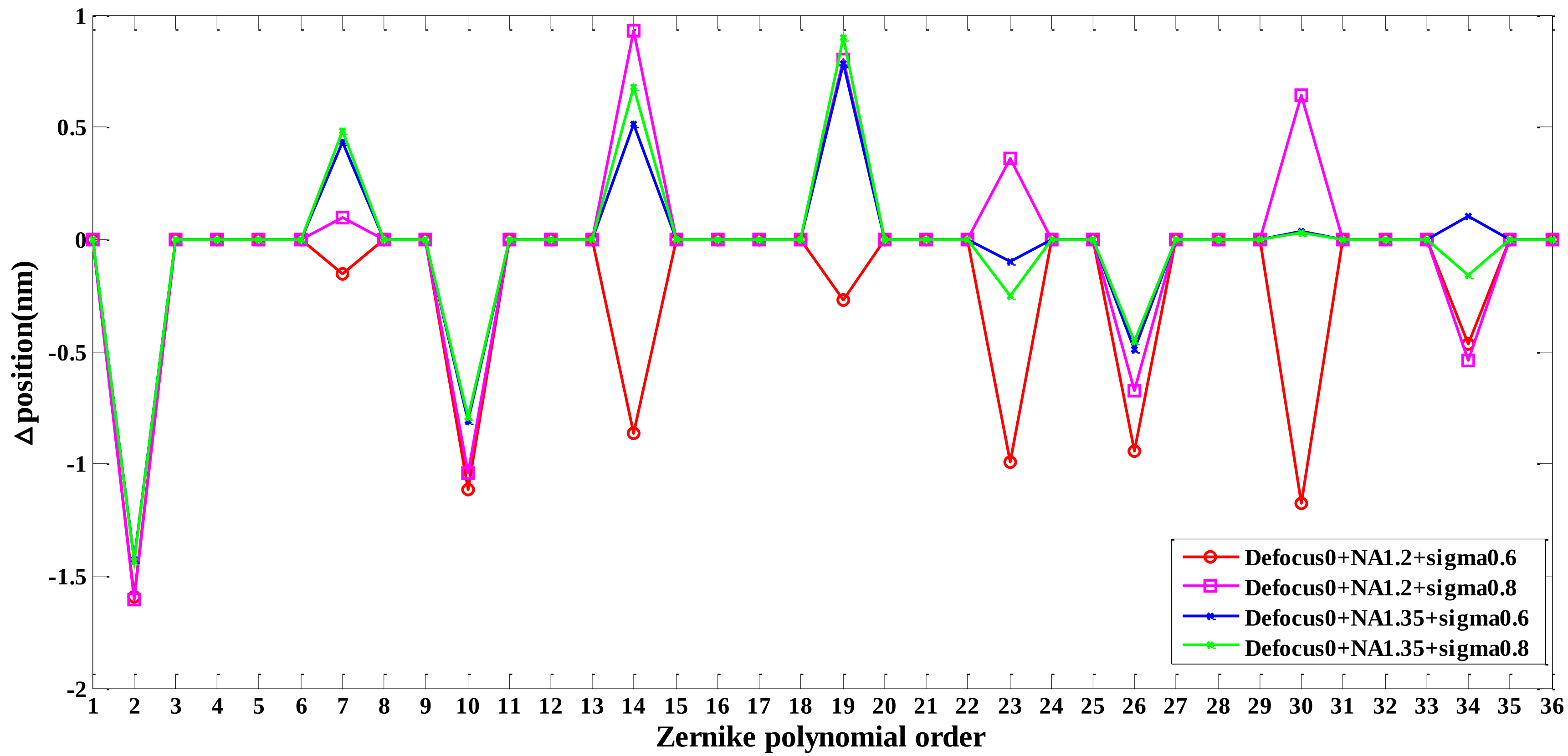
CD result



Compared to the dense line, more diffraction orders are collected by lenses and modulated by aberration for semi-dense pattern. So, the ΔCD is significantly increased

Pitch 200nm (semi-dense line)

position Result



The 1st Zernike polynomial is constant term, so the ΔCD and Δposition of the 1st term for all figures is 0

Result and discussion

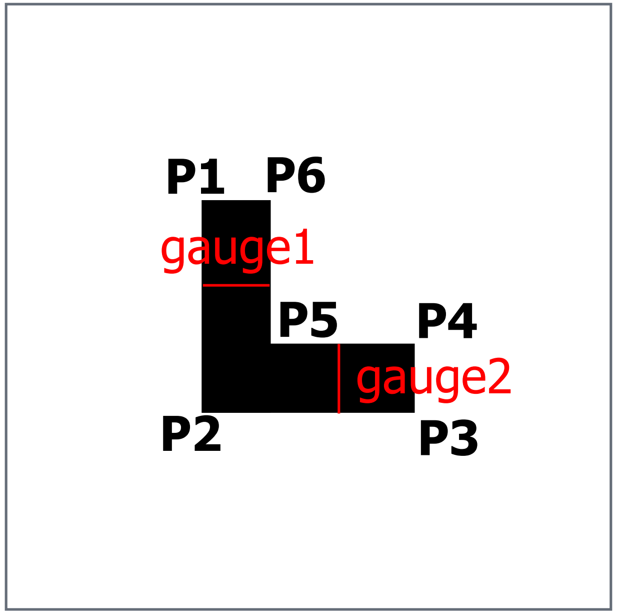
1D pattern

The maximum abs(ΔCD) is 1.31nm at Z9 for the configuration of no defocus, NA 1.35, pitch 200nm, sigma 0.8.

The maximum abs(Δposition) is 1.61nm at Z2 for configure of no defocus, NA 1.2, pitch 200nm, sigma 0.8.

Verified 2D pattern and setting

2D pattern



P1(-120,120)　P2(-120,-120)　P3(120,-120)
P4(120,-60)　P5(-60,-60)　P6(-60,120)

Reduction ratio 4:1

Wavelength 193nm

NA 1.35

Simulation domain 768nm×768nm

Illumination type:

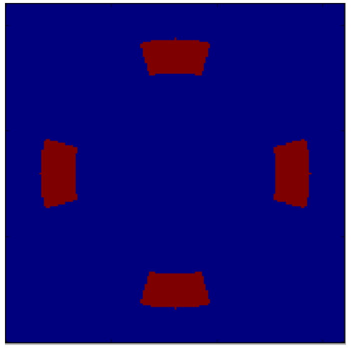
Quasar source with 30-degree span

TE-polarization

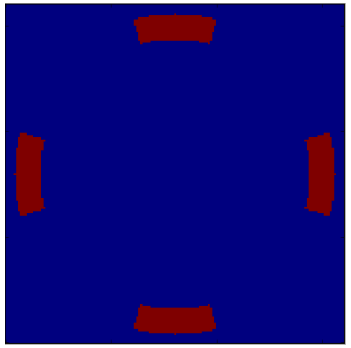
Wafer stack

80nm resist (n=1.69,k=0.05)

Substrate Si (n=0.883,k=2.778)



sigma 0.6/0.8



sigma 0.8/0.95

Optional parameter:

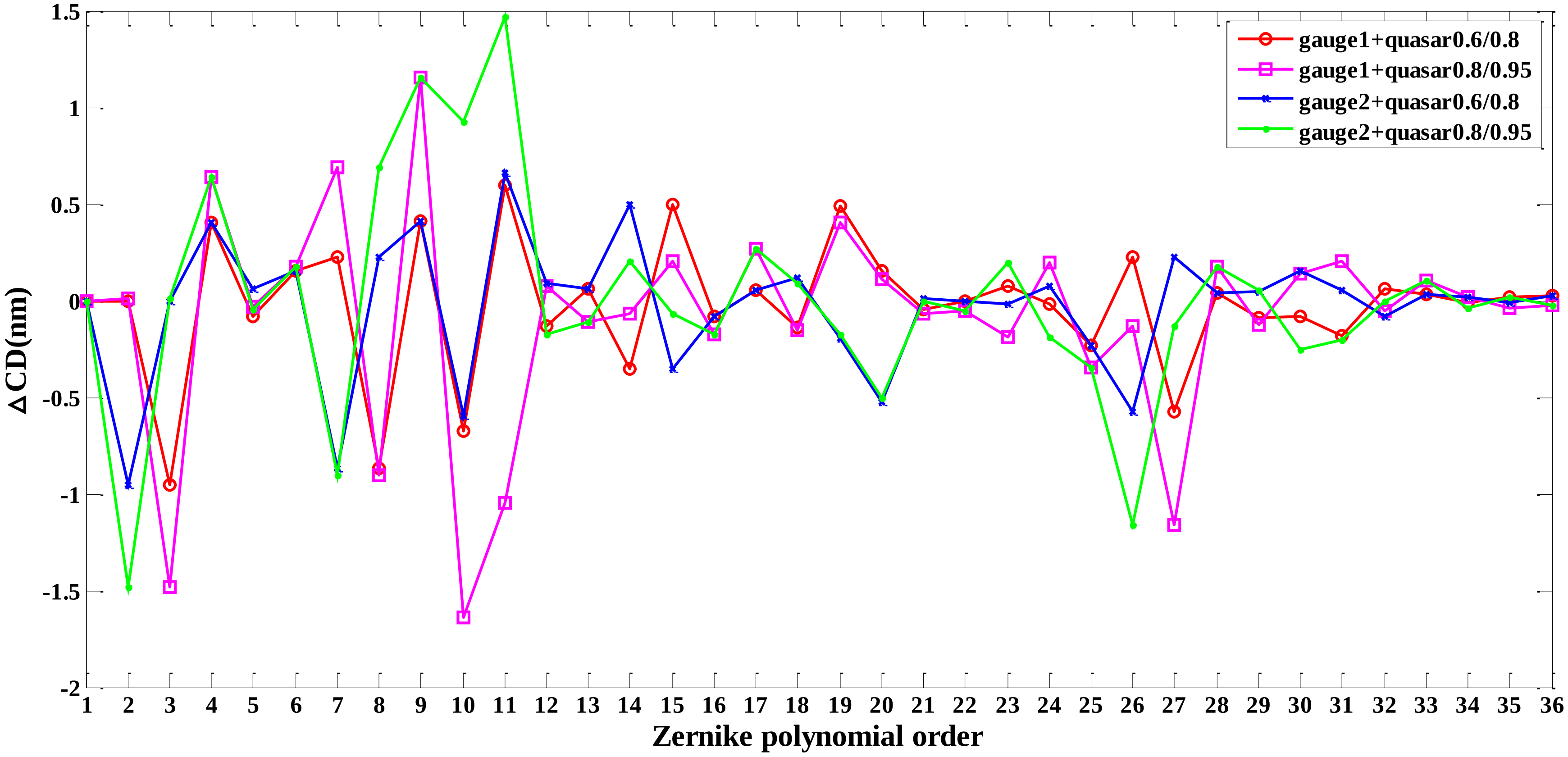
illumination sigma 0.6/0.8 or 0.8/0.95

Result and discussion

2D pattern

CD result

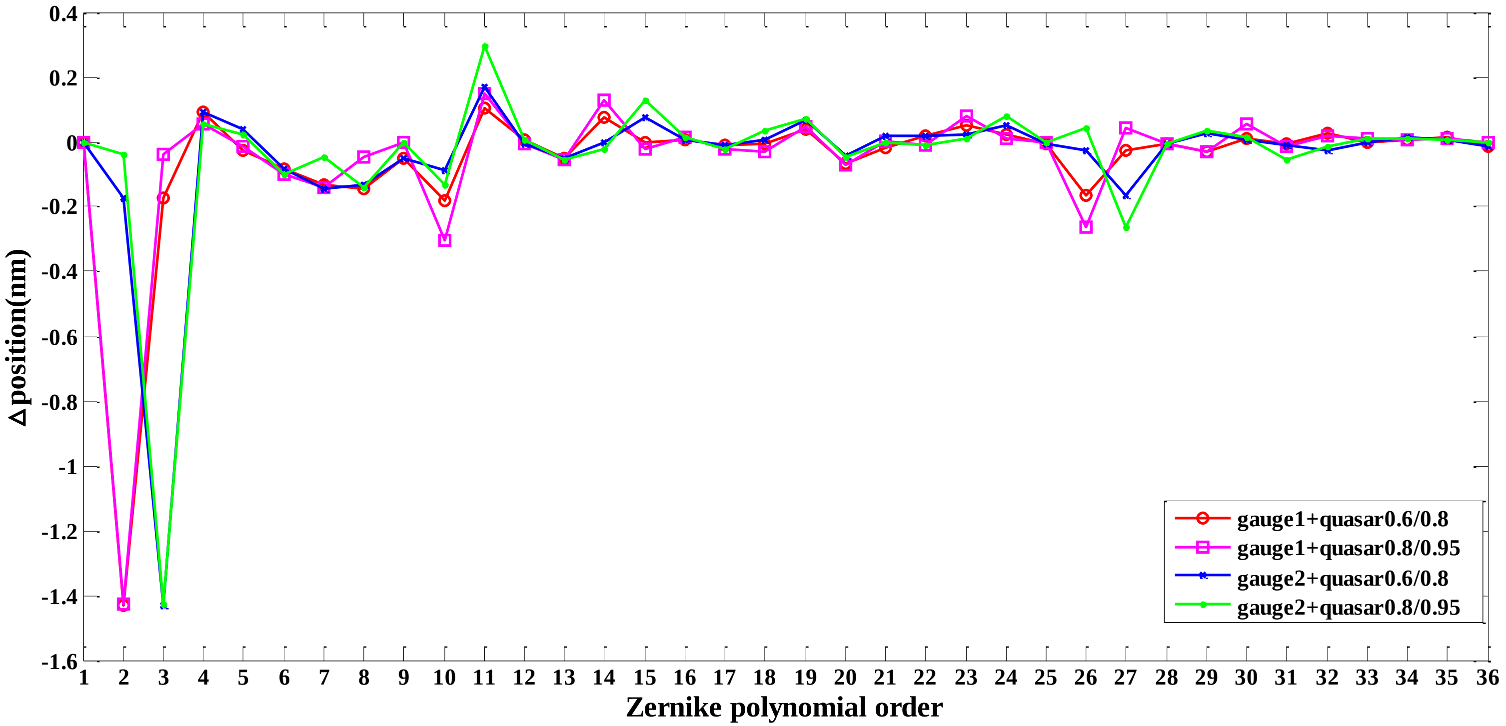
Two gauges are symmetry, so we only need to focus on one gauge's data



Due to the complexity of mask spectrum, almost all aberration terms can lead to ΔCD.

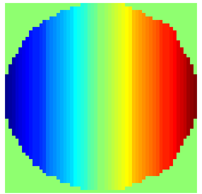
2D pattern

position result

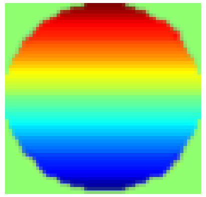


For both 1D and 2D patterns, the Z2 or Z3 term would create the largest Δposition.

2



3



2D pattern

The maximum abs(ΔCD) is 1.64nm at Z10 for the configuration of inner sigma 0.8 and outer sigma 0.95.

The maximum abs(Δposition) is 1.43nm at Z2 for the configuration of inner sigma 0.8 and outer sigma 0.95.

- Resolution Limitation
- Lenses aberration
- Induced Effect and Analysis
- **Summary and Discussion**

Summary and future work

1. The impact of aberration on CD and position is determined by diffraction order on the pupil.
2. For 1D pattern, we can predict every aberration term's impact on CD and position; For 2D pattern, almost all Zernike terms would impact lithography CD.
3. The maximum variation of CD and position for specific configure is close to ±1.5nm.
4. To include the aberration signature in mask layout synthesis should eliminate the above CD or position errors on the wafer.

全芯智造
AMEDAC

Thank You!

0551-65888288
marketing@amedac.com
www.amedac.com