

Zone Plate tilt simulation

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Outline

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- Multislice basics

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- Introduction

- Tilt tolerance

- Implementation details

- Results

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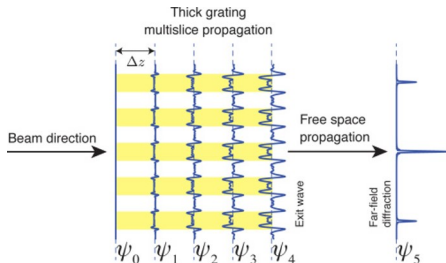
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What is multislice

- ▶ Method to calculate x-ray wave propagation through arbitrary discrete objects ¹
- ▶ Involves breaking up the object into multiple "slices" and alternate propagation between the slice and refraction at the slice.



¹[LJ15][LWJ17]

Number of slices.

- ▶ Li et al² showed that by increasing the number of slices, the multislice method gives identical results to CWT with the advantage that it can work with arbitrary structures on a discretized grid.
- ▶ It was empirically shown that the step size to achieve this is

$$\Delta z = \frac{\epsilon_2}{\epsilon_1^2} \frac{\Delta x^2}{\lambda}$$

(Δx is the pixel size, λ is the wavelength and ϵ_1, ϵ_2 are ≈ 0.1 .)

- ▶ Thus, we need more slices at lower energy.

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Need for multislice simulation

- ▶ Advances in nanofabrication processes have led to fabrication of zone plates with high aspect ratios³. As the thickness of zone plates increases and the outermost zone width decreases, aspect ratios as high as 500:1 have been achieved⁴.
- ▶ These high aspect ratios have made the zone plates very sensitive to tilt alignment errors while also making them behave like volume gratings⁵.
- ▶ This makes previous results that calculate tilt tolerance that assume zone plates to be thin optical elements invalid and require new calculations for the same.

³[CS14],[JVCP⁺07]

⁴[LWD⁺17]

⁵[MS92],[Sch97]

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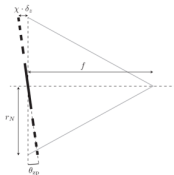
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Previous results

- ▶ Myers⁶ and Young⁷ had calculated the tilt tolerance using optical path lengths. Jacobsen et al⁸ took the depth of focus limits into account
- ▶ Jacobsen et al.⁹ approached the problem by relating the tilt angle to a factor of depth of focus.



- ▶ As stated earlier, these results don't take into account the thickness of the zone plates.

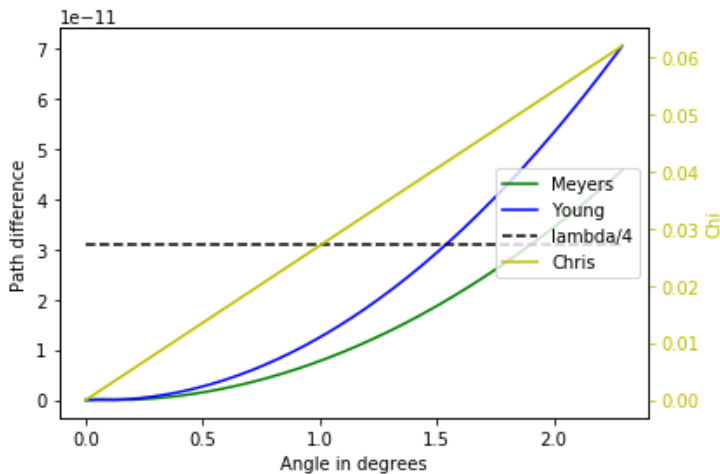
⁶[Mye51]

⁷[You72]

⁸[JWA⁺91]

⁹[eae]

Previous results



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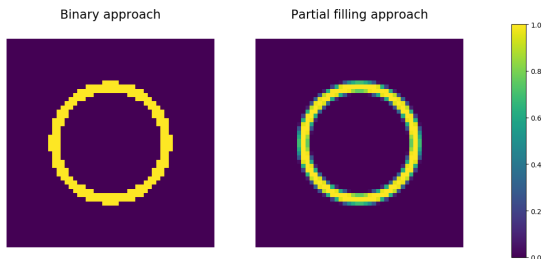
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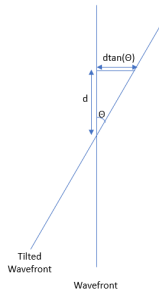
Partial filling

- ▶ Pixel sizes are chosen to be no larger than 0.25 times the outermost zone width to ensure adequate sampling.
- ▶ Partial filling is done to avoid jagged edges.



Simulating tilt

- ▶ To simulate tilt, the phase of the incoming plane wave is modified instead of laboriously tilting the zone plate in three dimensions.
- ▶ A plane wave input that is perfectly aligned with the zone plate would correspond to a grid where all the values are set to 1



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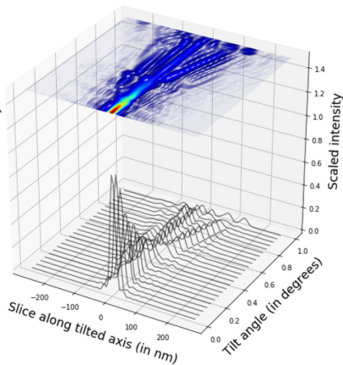
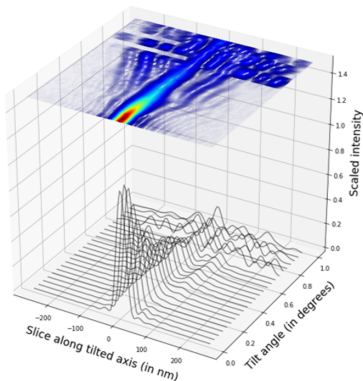
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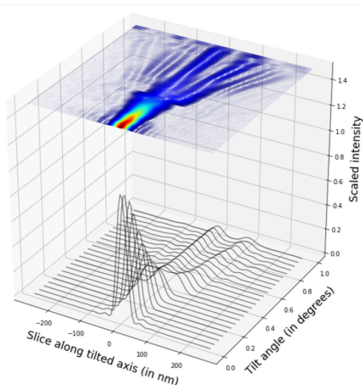
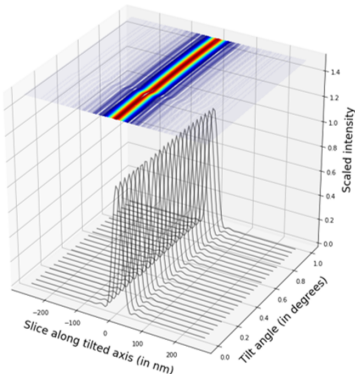
Dependence on number of zones

- ▶ Zone plate focal profiles along axis of tilt. Both zone plates are 8 microns thick but the one on the left has 200 zones and the one on the right has 500.



Dependence on thickness

- ▶ Zone plate focal profiles along axis of tilt. Both have 200 zones while the one of the left is 0.5 microns thick and the one on the right is 10 microns thick.



Summary

- ▶ Zone plate tilt tolerance depends on thickness of zone plate.
- ▶ Need better models to quantify tilt tolerance of zone plates.
- ▶ Multislice allows us to predict this.
- ▶ Future
 - ▶ SRW integration ?

Acknowledgements

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- ▶ **Kenan Li** SLAC National Accelerator Laboratory.
- ▶ **Michael Wojcik** XSD, APS.

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