Exploring Polarization-Splitting Grating Couplers on a Silicon-Nitride platform at 1550 nm

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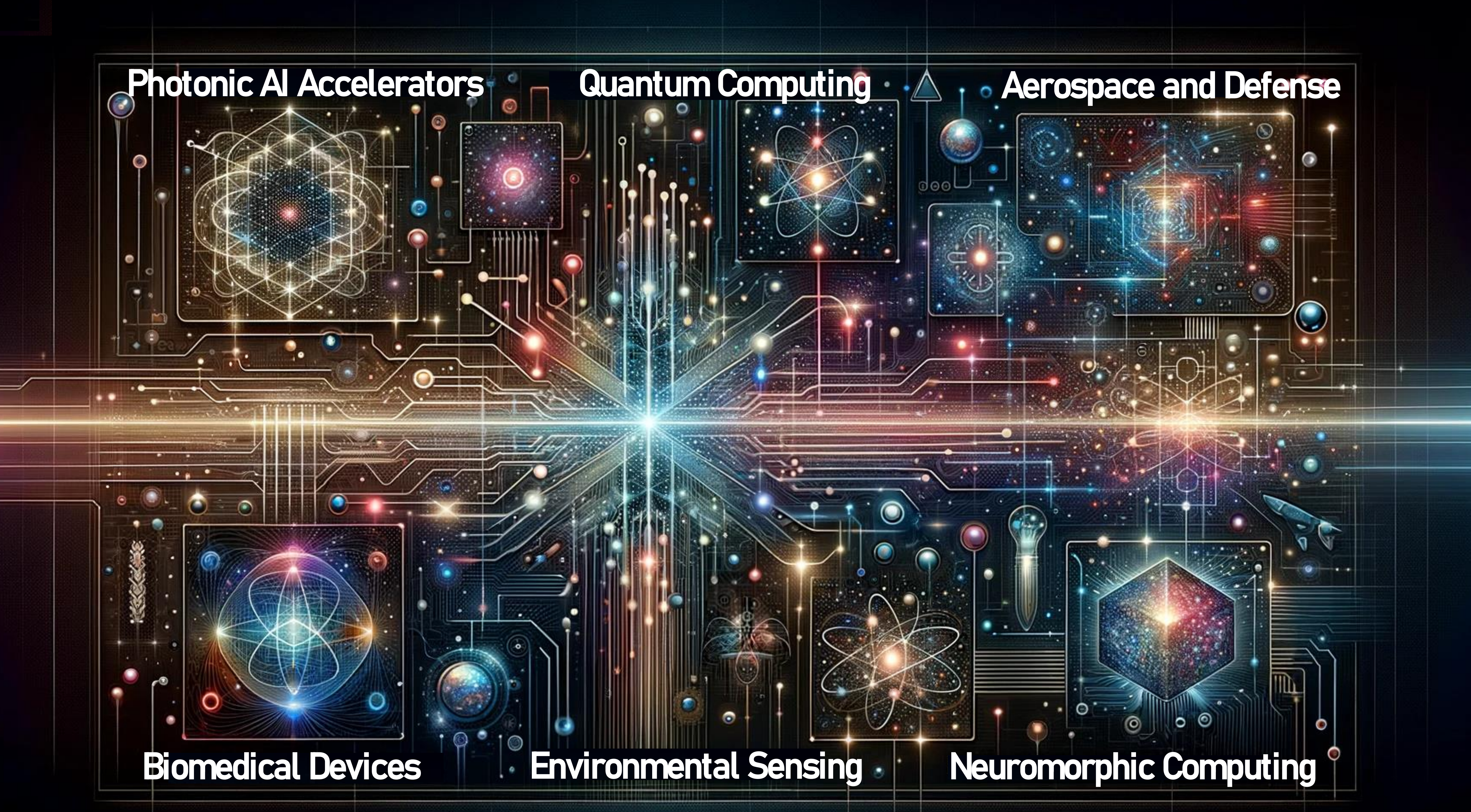
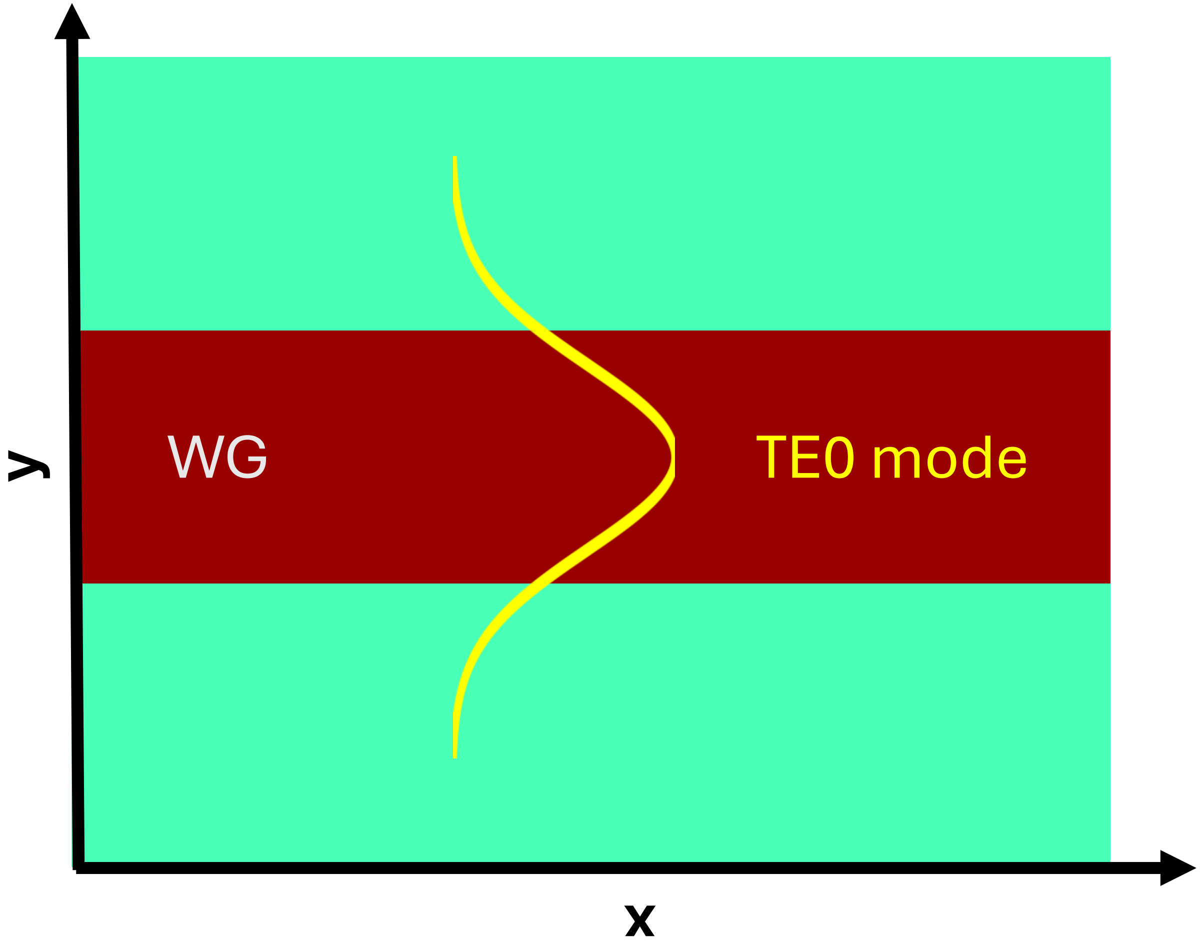


Image from ChatGTP

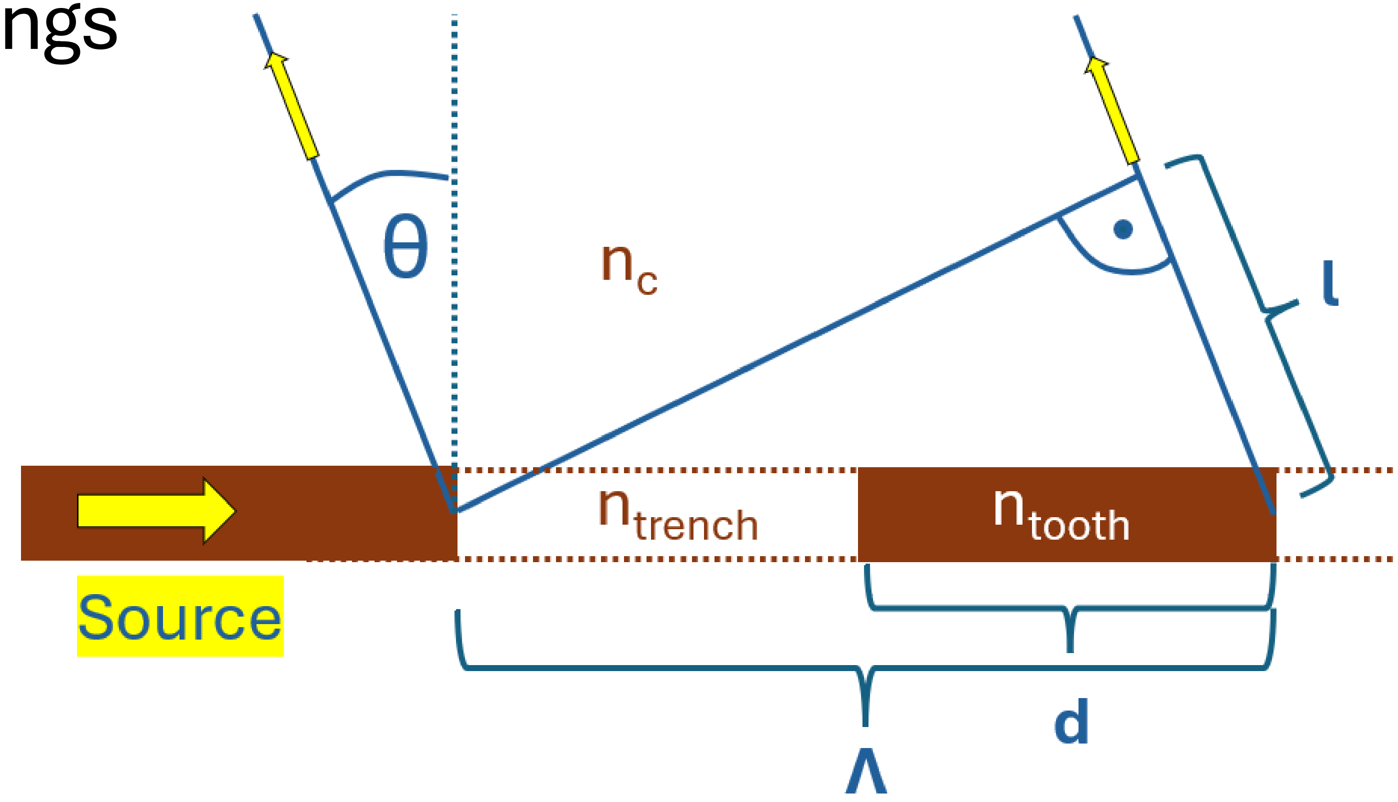
Modes and effective indices



The Bragg equation for gratings

Important parameters:

- Period **Λ**
- Toothlength **d**
- Negative diffraction angle **θ**
- Refractive indices $\mathbf{n_c} = \mathbf{n_{trench}}$ and $\mathbf{n_{tooth}}$
- **l** = sin(**-θ**) * **Λ**

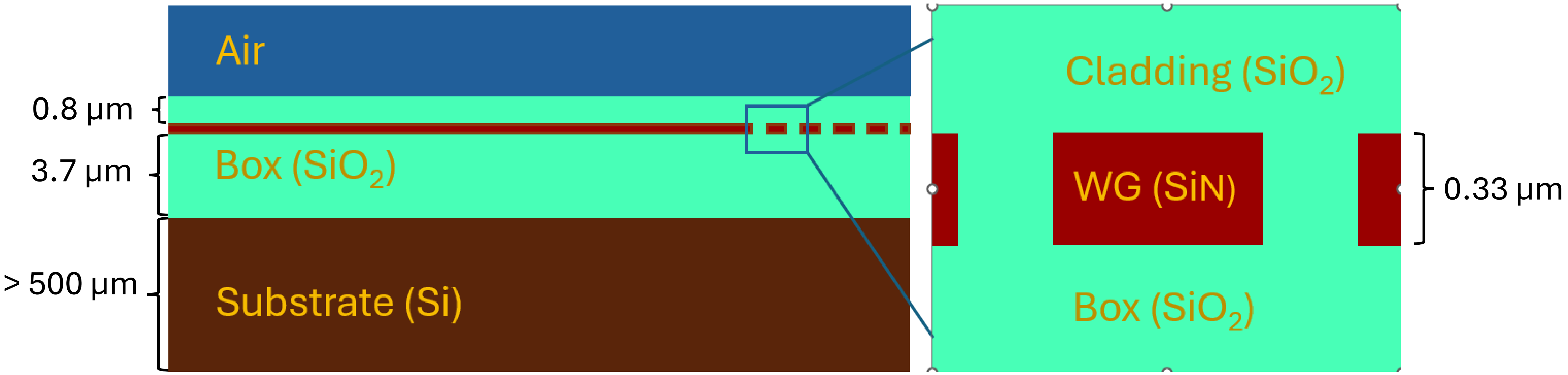


$$n_{eff} \cdot \Lambda - n_c \cdot \Lambda \cdot sin(\theta) = \lambda$$ (Bragg equation)

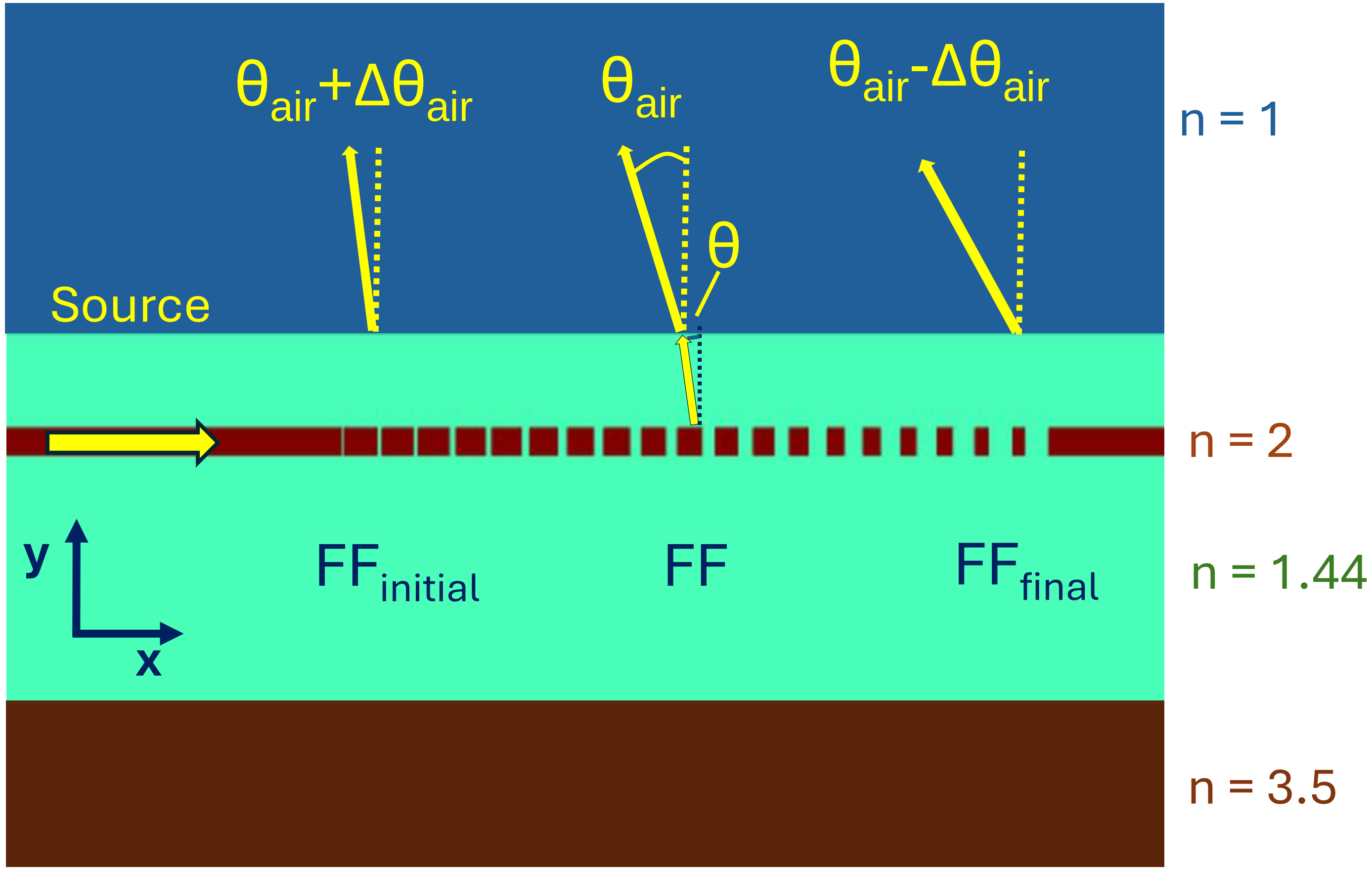
$$n_{eff} = FF \cdot n_{tooth} + (1 - FF) \cdot n_{trench} \ ; \quad FF := \frac{d}{\Lambda}$$

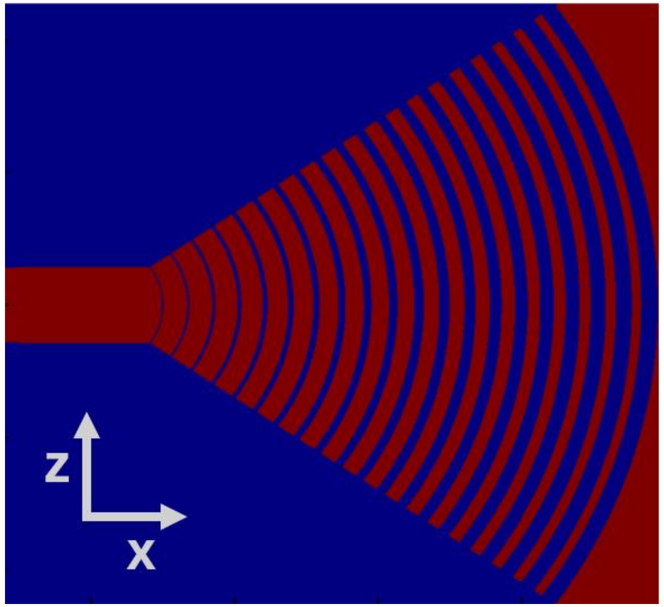
SiN platform

Low loss at 1550 nm



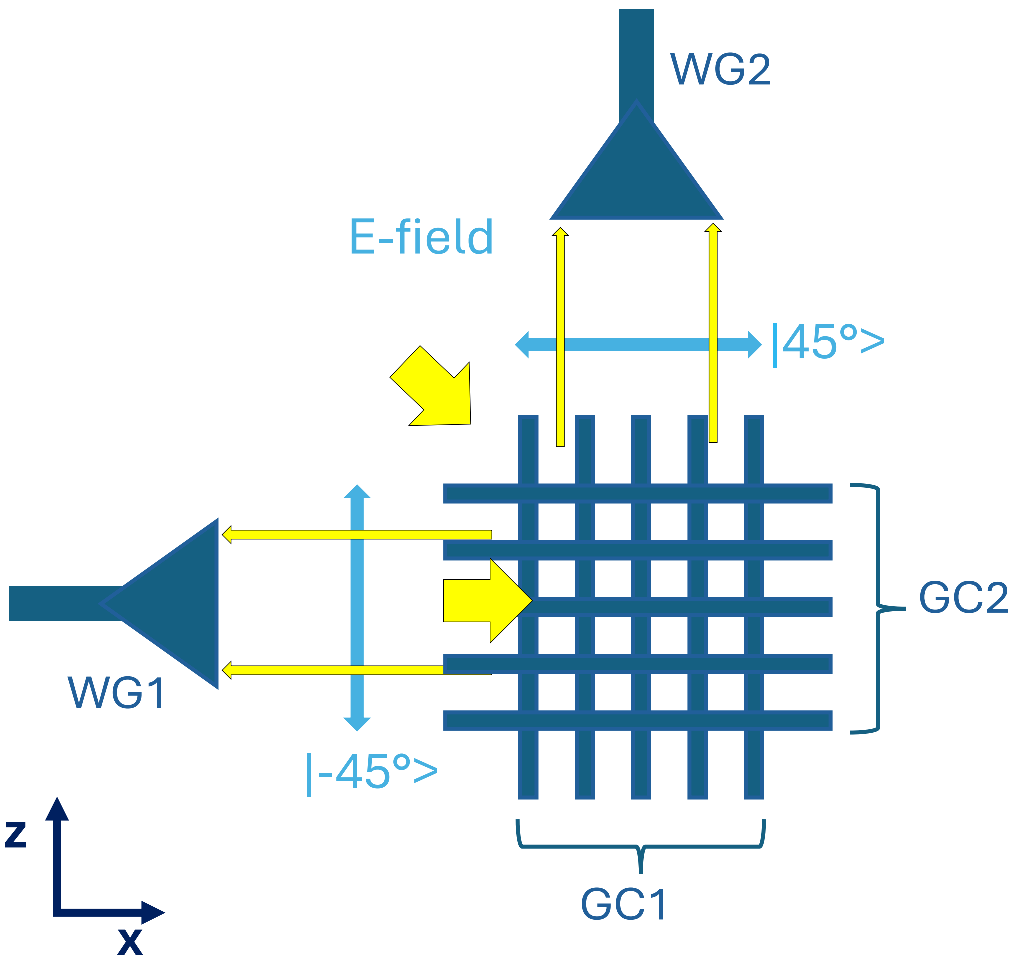
Self-imaging effect with apodized gratings

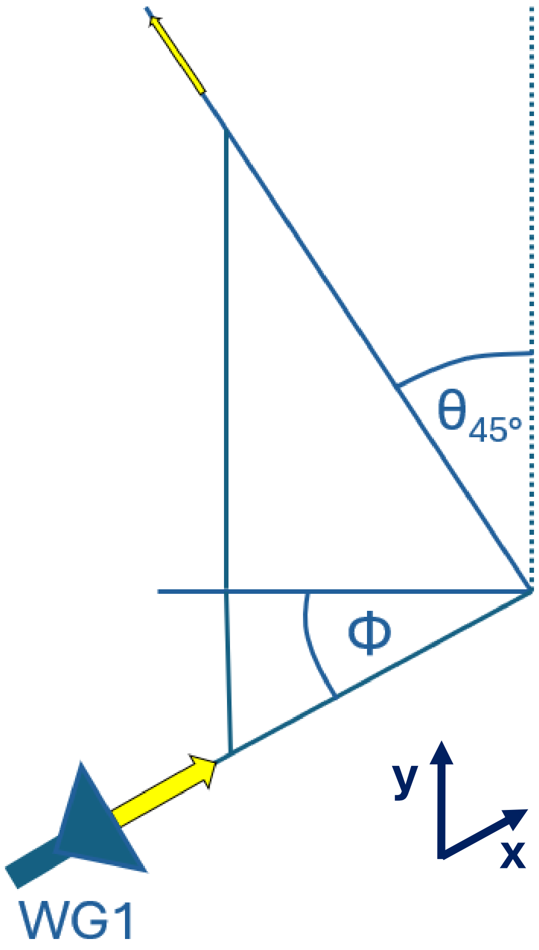




- Curved gratings achieve a focusing effect in transverse direction
- Circular gratings are a good approximation of the optimal shape

Polarization-Splitting Grating Coupler (PSGC)





- Symmetrical design of PSGC
  => $\phi = 45°$
- In-house fiber array has polishing angle of 8 degrees
  => $\theta_{45°} = 8°$

Polarization-Splitting Grating Coupler (PSGC)

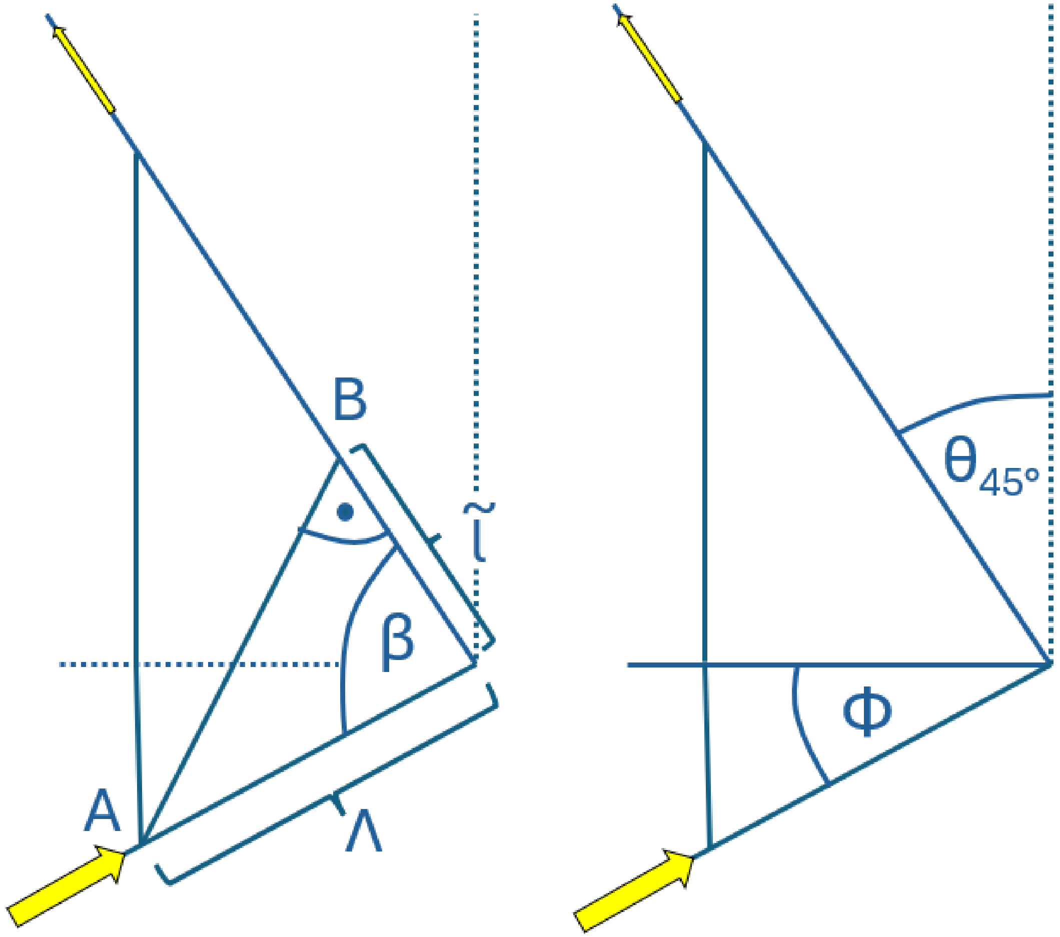
$$\cos\beta = \sin\theta_{45^\circ} \cdot \cos\phi$$

$$n_{eff} \cdot \Lambda - n_c \cdot \Lambda \cdot sin(\theta) = \lambda \quad \text{(Bragg 2D)}$$

$$n_{eff} \cdot \Lambda + n_c \cdot \Lambda \cdot \cos(\beta) = \lambda \quad \text{(Bragg 3D)}$$

⬇

$$\sin(\theta) = -\cos(\beta)$$

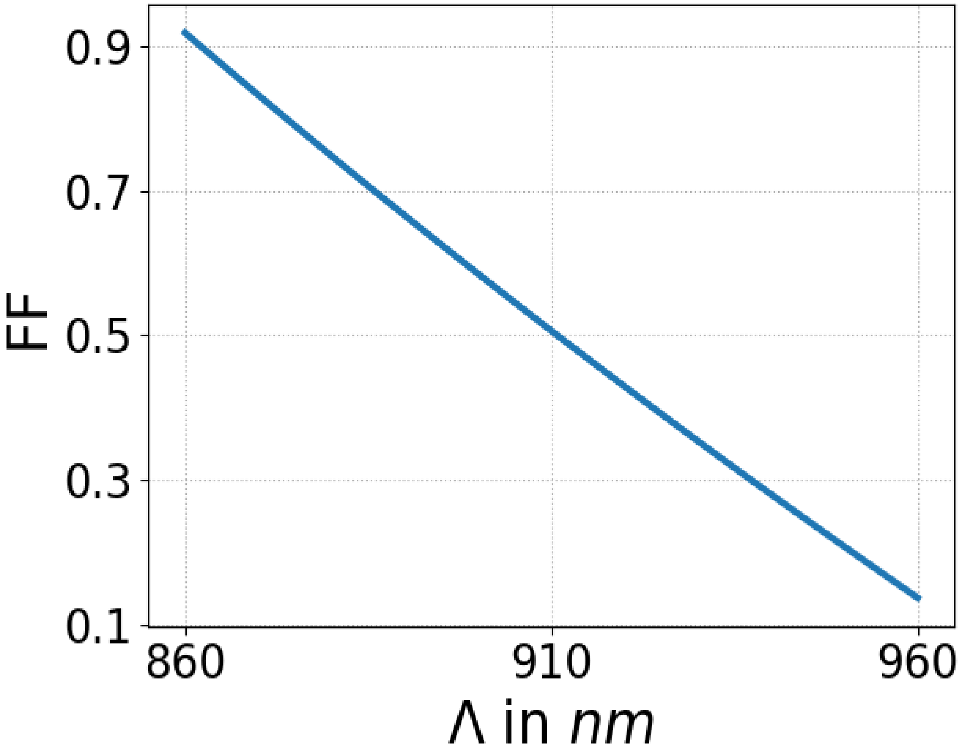


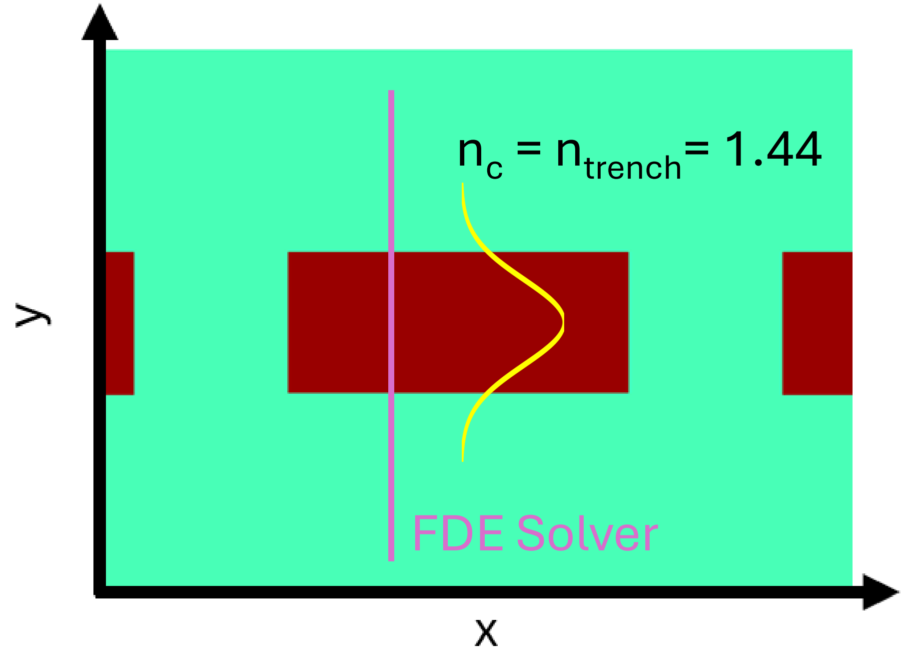
➡ $$\theta = -\arcsin\left(\sin\theta_{45^\circ} \cdot \cos\phi\right) \approx -5.65^\circ$$

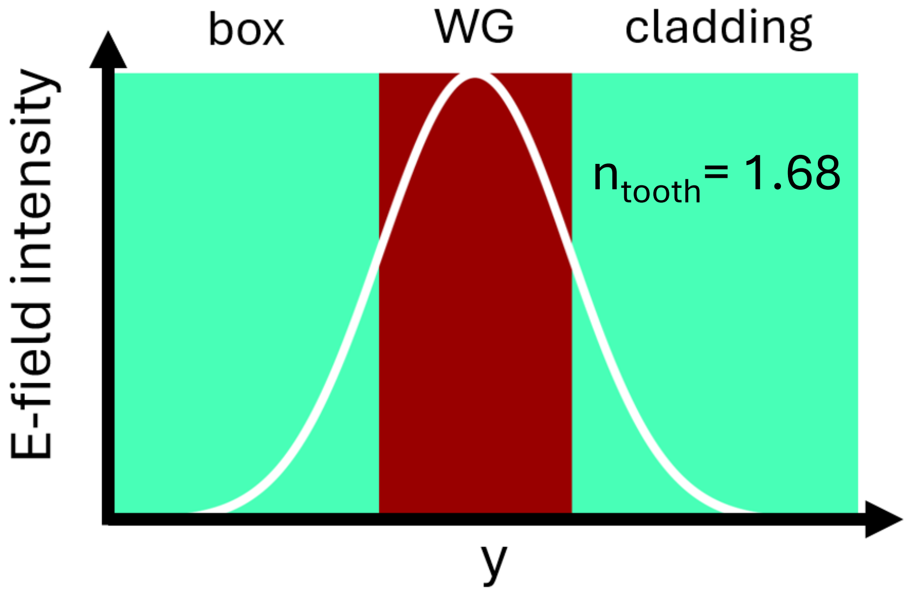
Simulation of 2D GC

$$\frac{FF_{initial} + FF_{final}}{2} = FF = \frac{n_c \cdot \sin\theta + \frac{\lambda}{\Lambda} - n_{trench}}{n_{tooth} - n_{trench}}$$

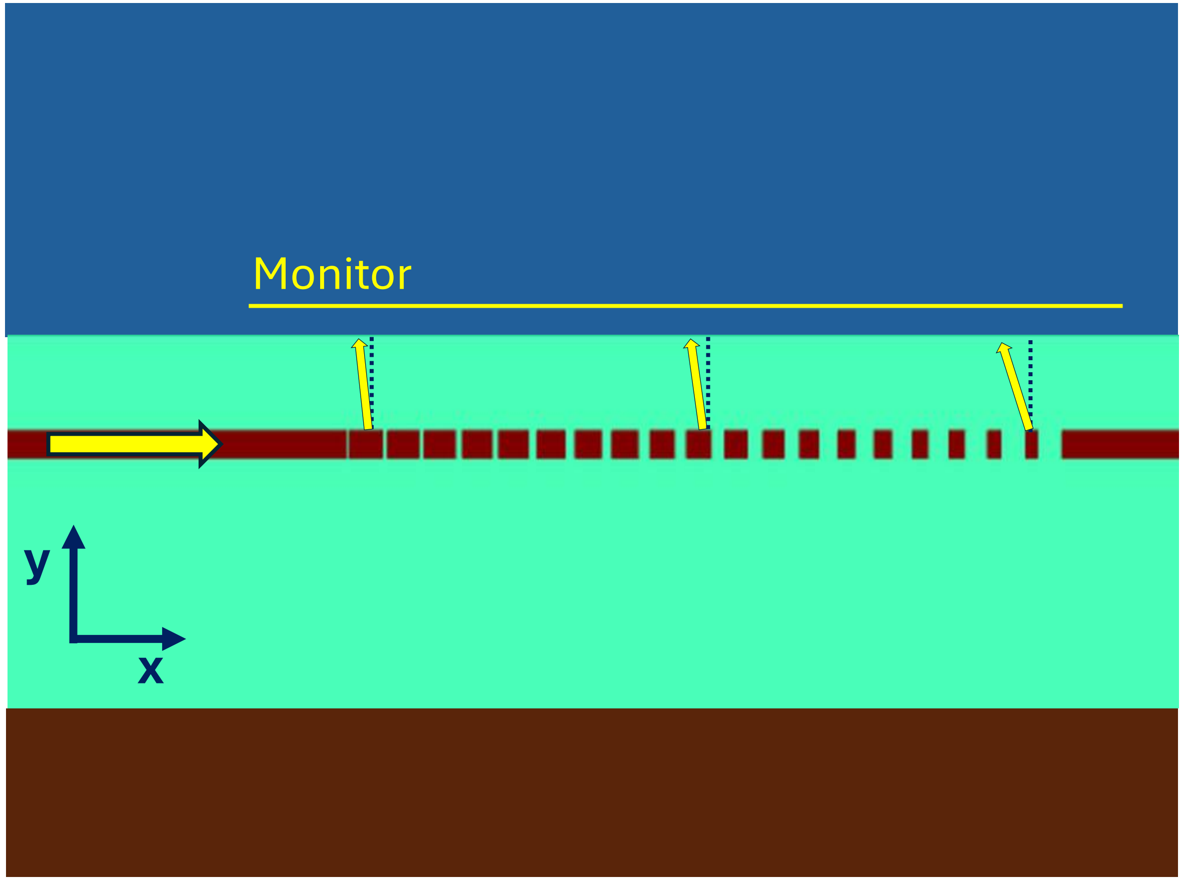
- $\theta = -5.65°$
- $\lambda = 1550$ nm
- FF and Λ are coupled variables
- FF is composed of $FF_{initial}$ and FF_{final}



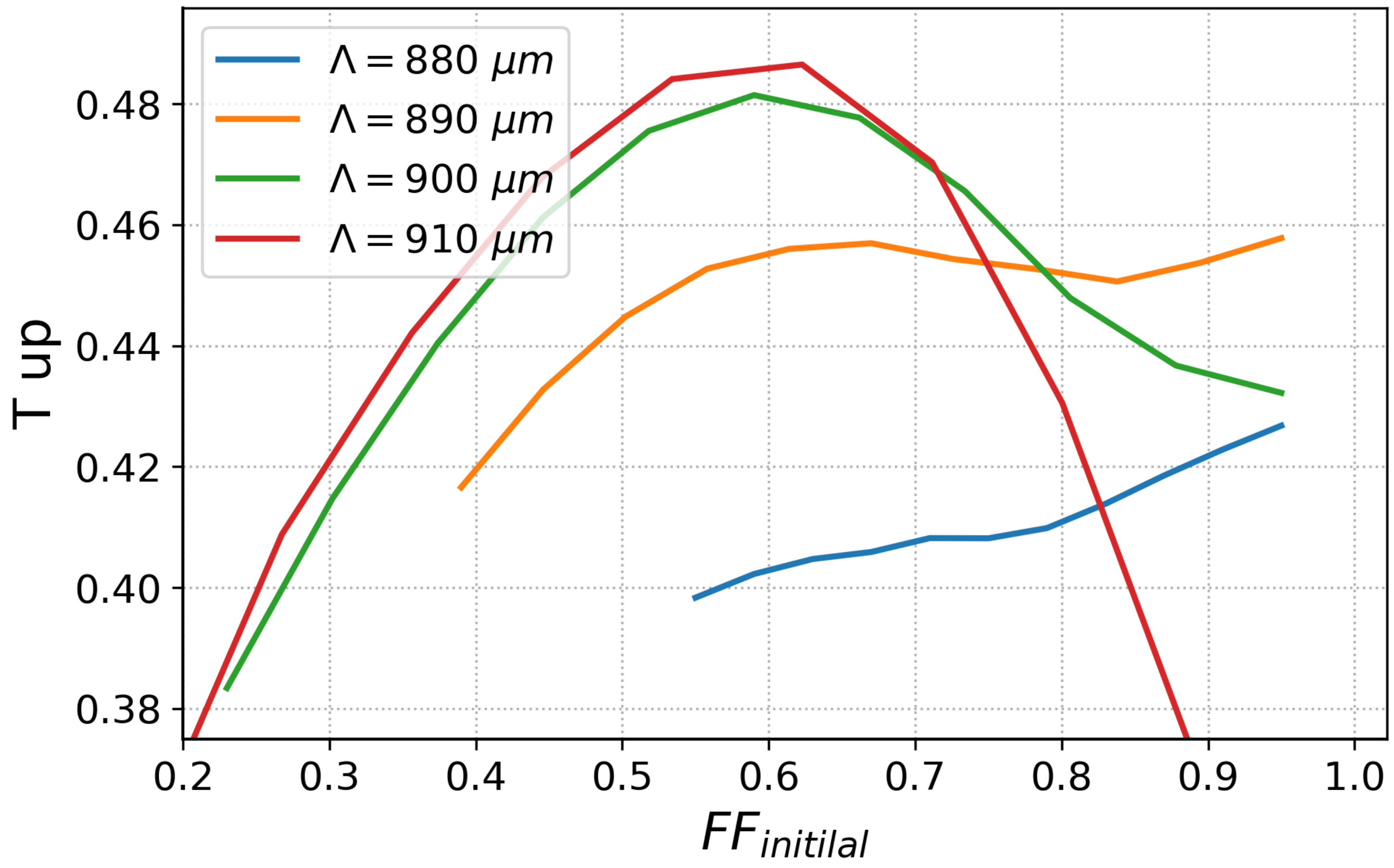


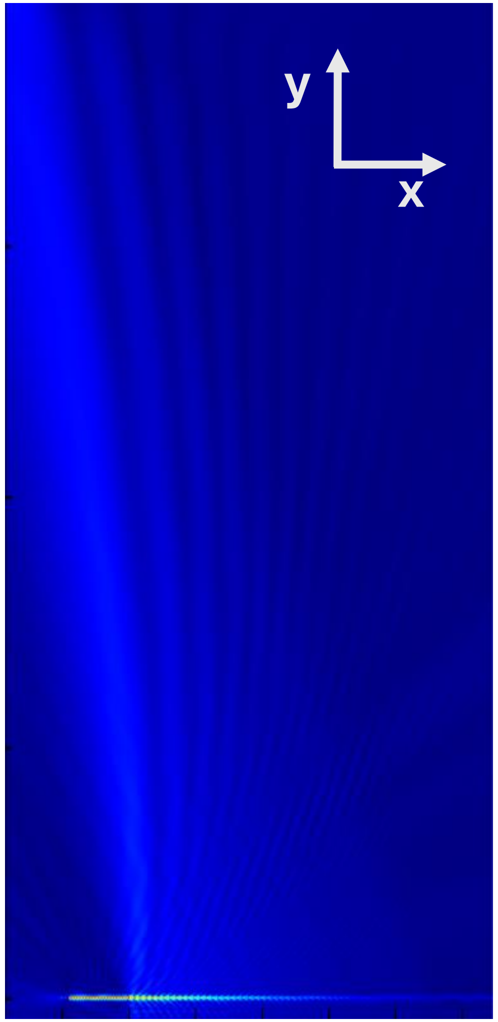


Simulation of 2D GC

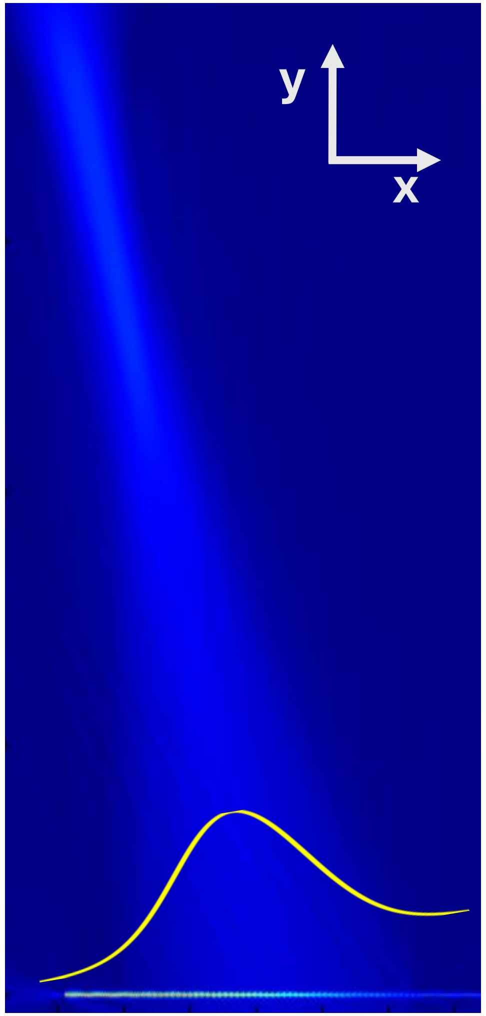


Simulation of 2D GC





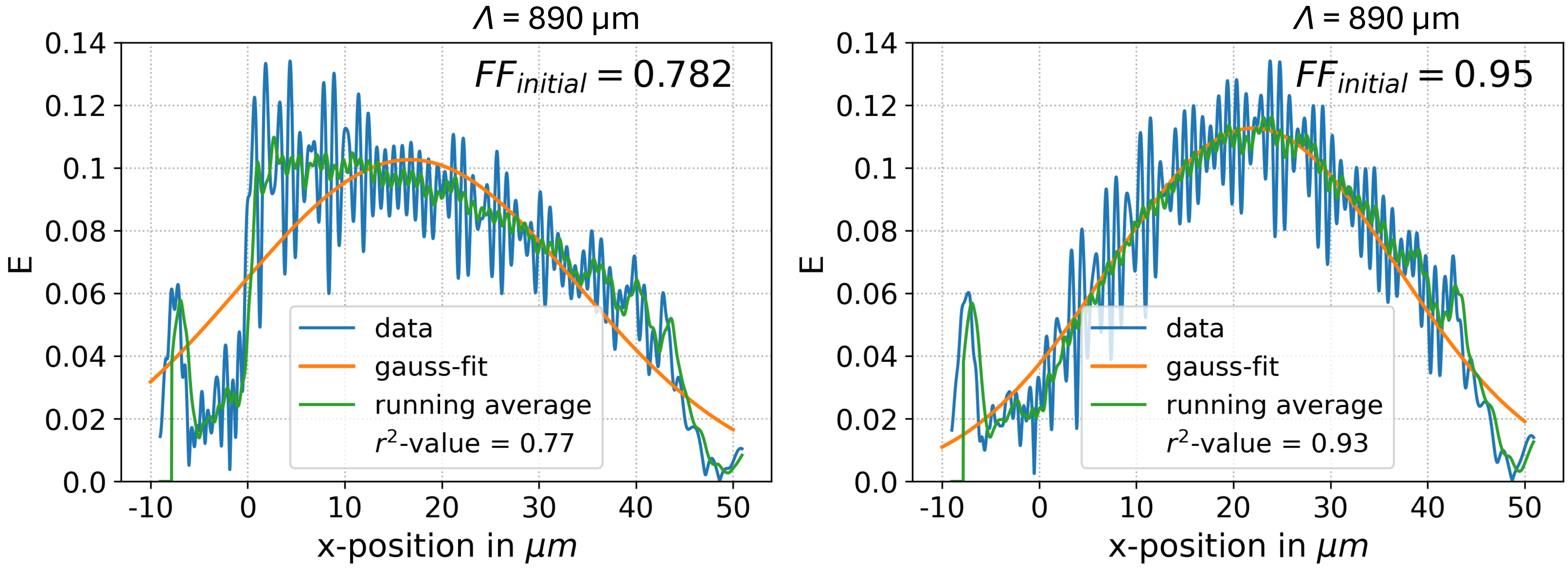
Λ = 910 μm
$FF_{initial}$ = 0.6



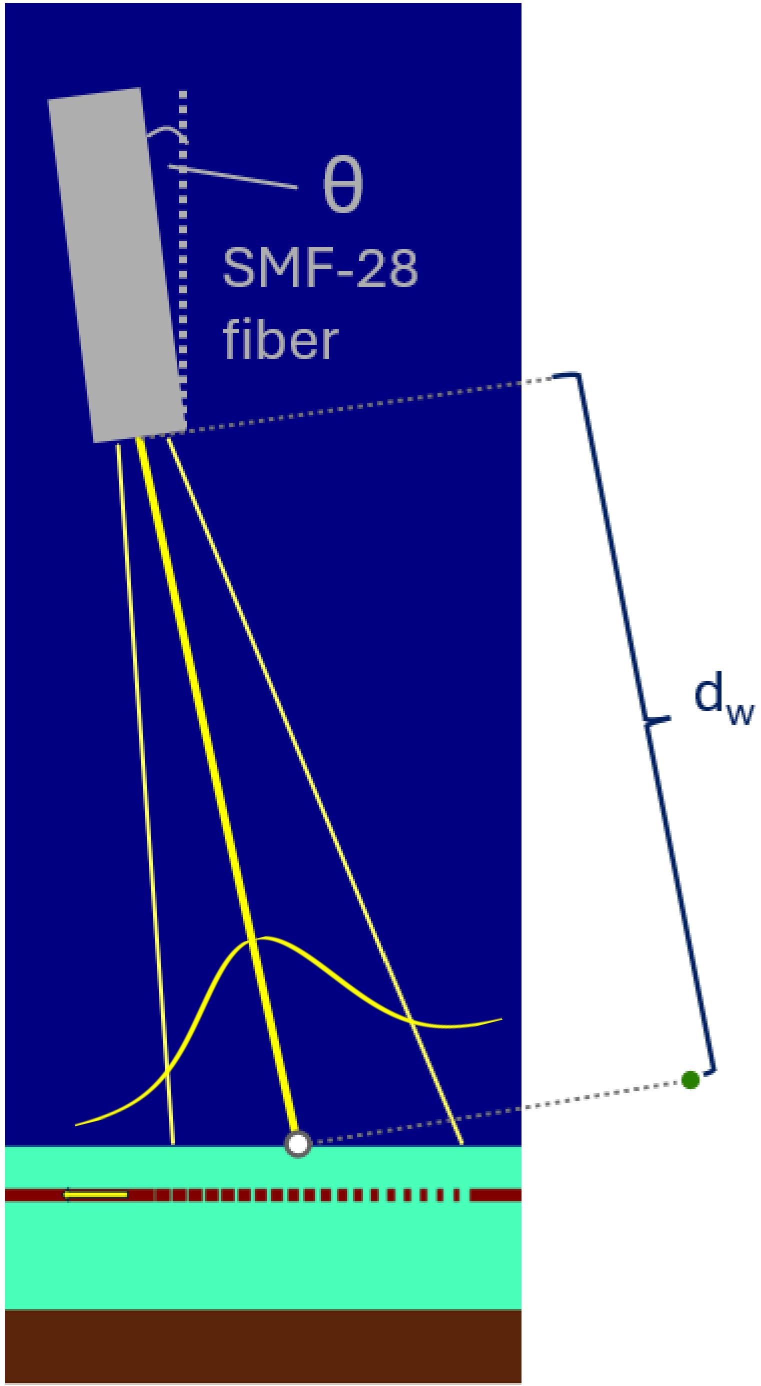
Λ = 890 μm
$FF_{initial}$ = 0.95

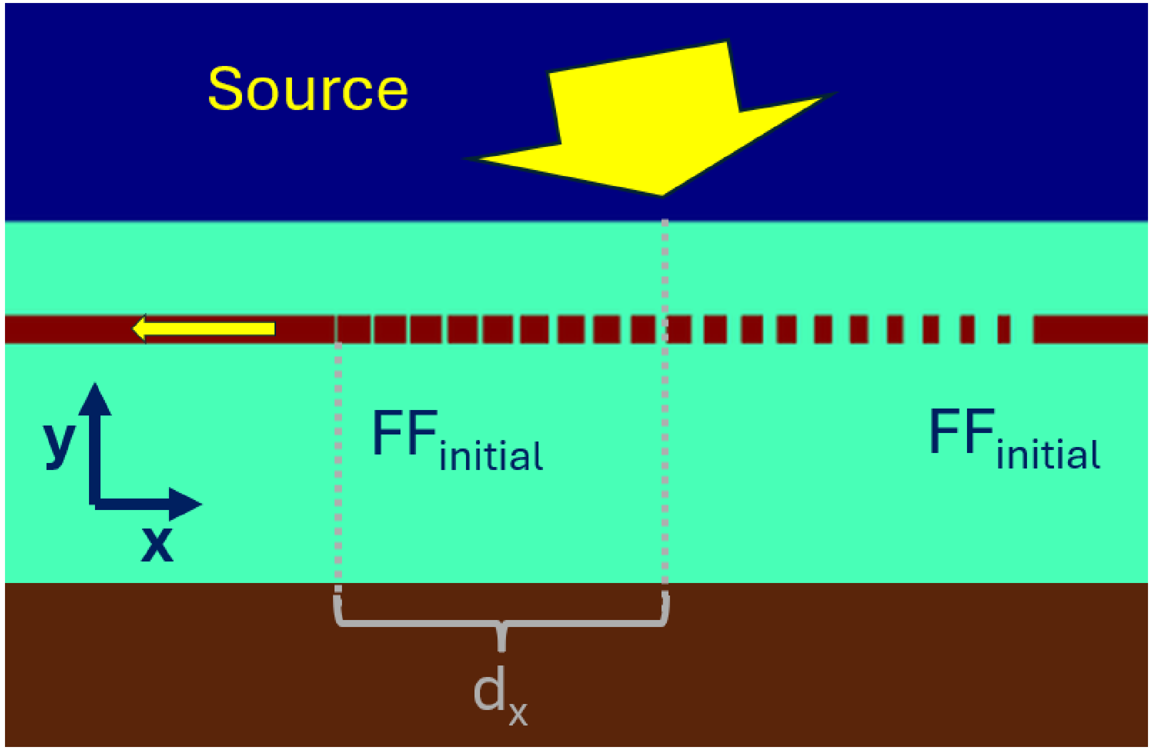
Simulation of 2D GC

- Best Gauss-fit for maximal $FF_{initial}$
- To be determined: optimal value for Λ between 880 and 900 µm



Refinement of simulation setup: in-coupling configuration





d_w = [90, 290] μm
d_x = [17, 22] μm
Λ = [880, 900] μm

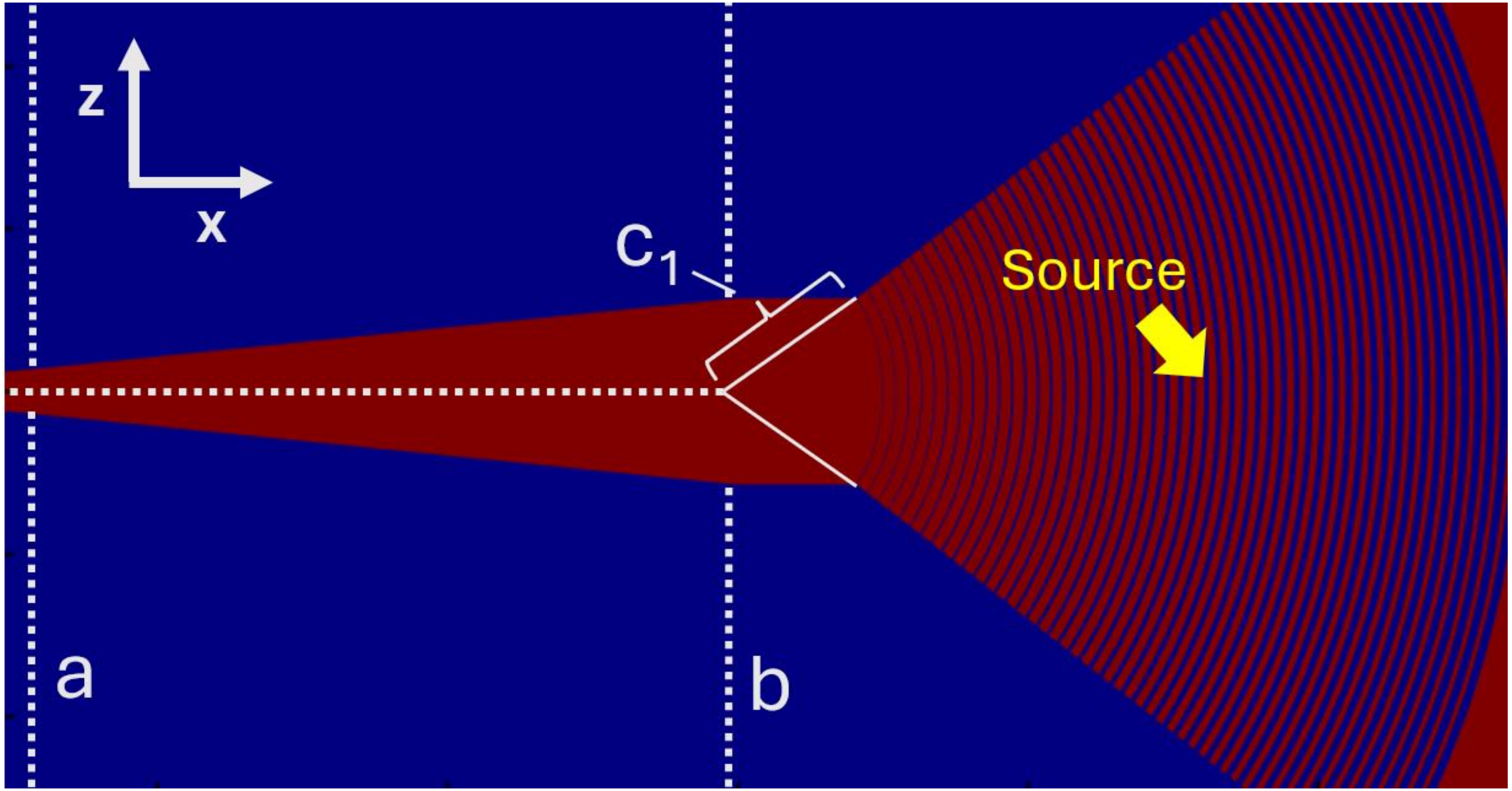
Simulation

d_w = 190 μm
d_x = 19 μm
Λ = 892 μm

Distances of the source from the chip d_w and x-position d_x become relevant.

T = 43.8% (mesh ~ 30 nm)
T = 51.8% (mesh ~ 1 nm)

Simulation results for circular gratings and rotated source



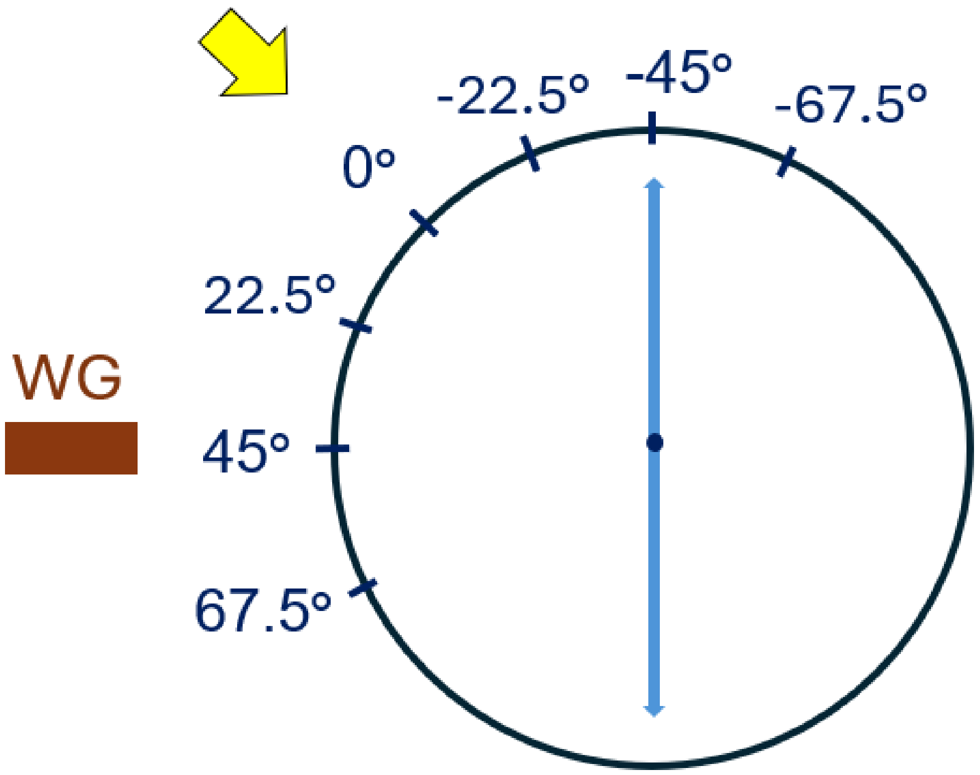
Transmission

2D GC	Pos b	Pos a
43.8%	17.4%	10.6%
3.6 dB	7.6 dB	9.7 dB

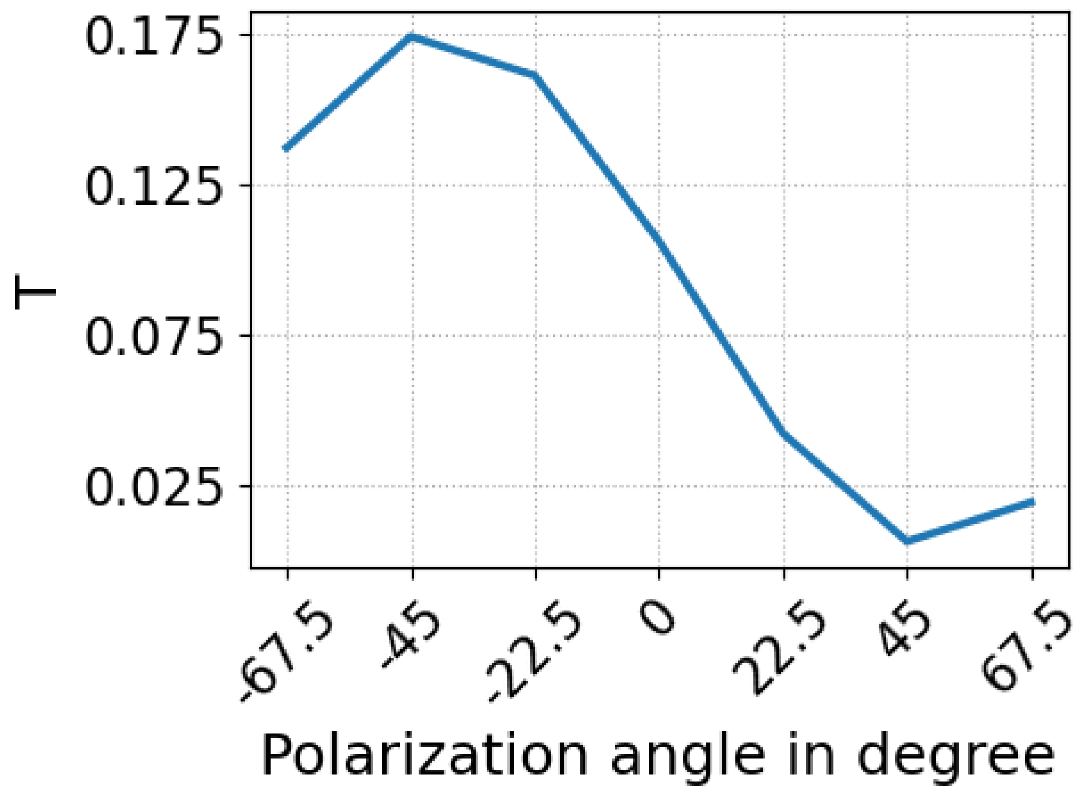
Less than 3 dB loss for a polishing angle of 11.35°:

- < 1.5 dB for circular gratings
- < 1.5 dB for rotating the source

Polarization angle dependence



E-field polarization

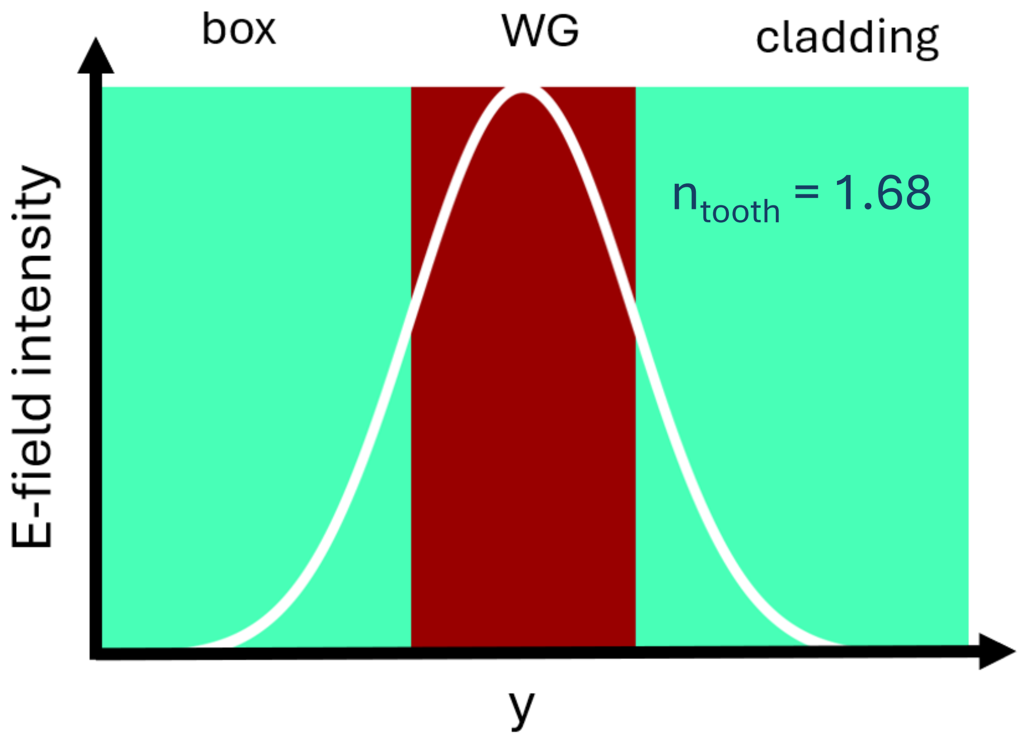


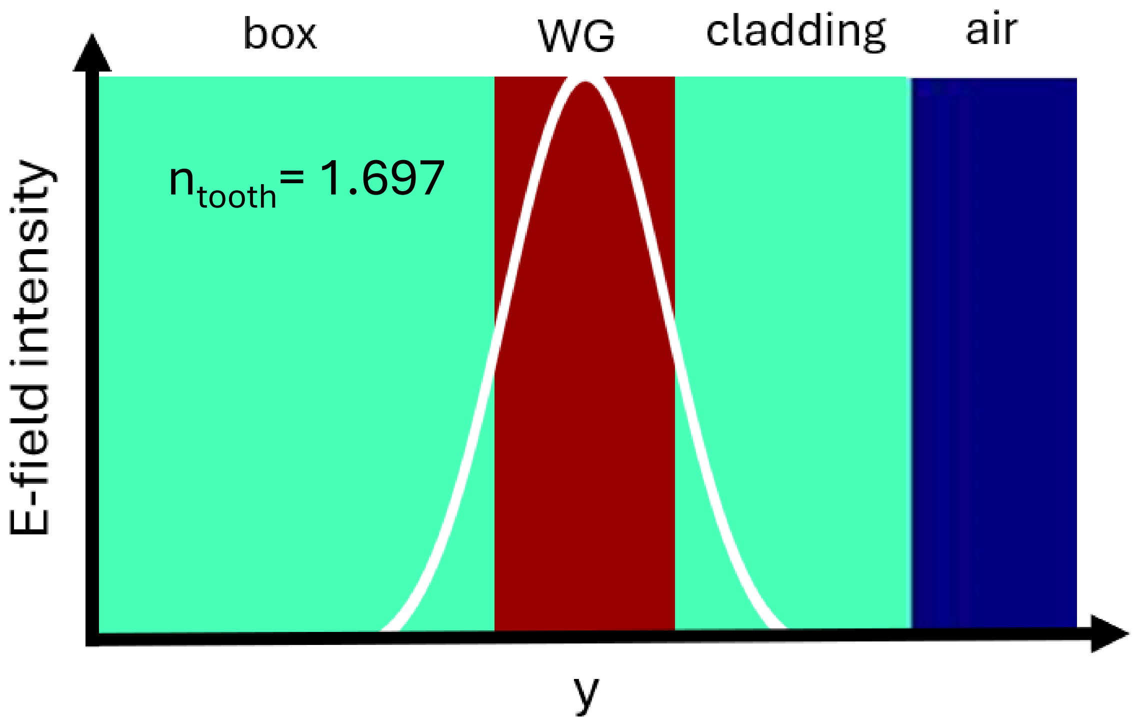
Outlook and improvement

1. Improvement suggestions for the 2D PC
2. Outlook PSGC

Possible improvements for the 2D GC

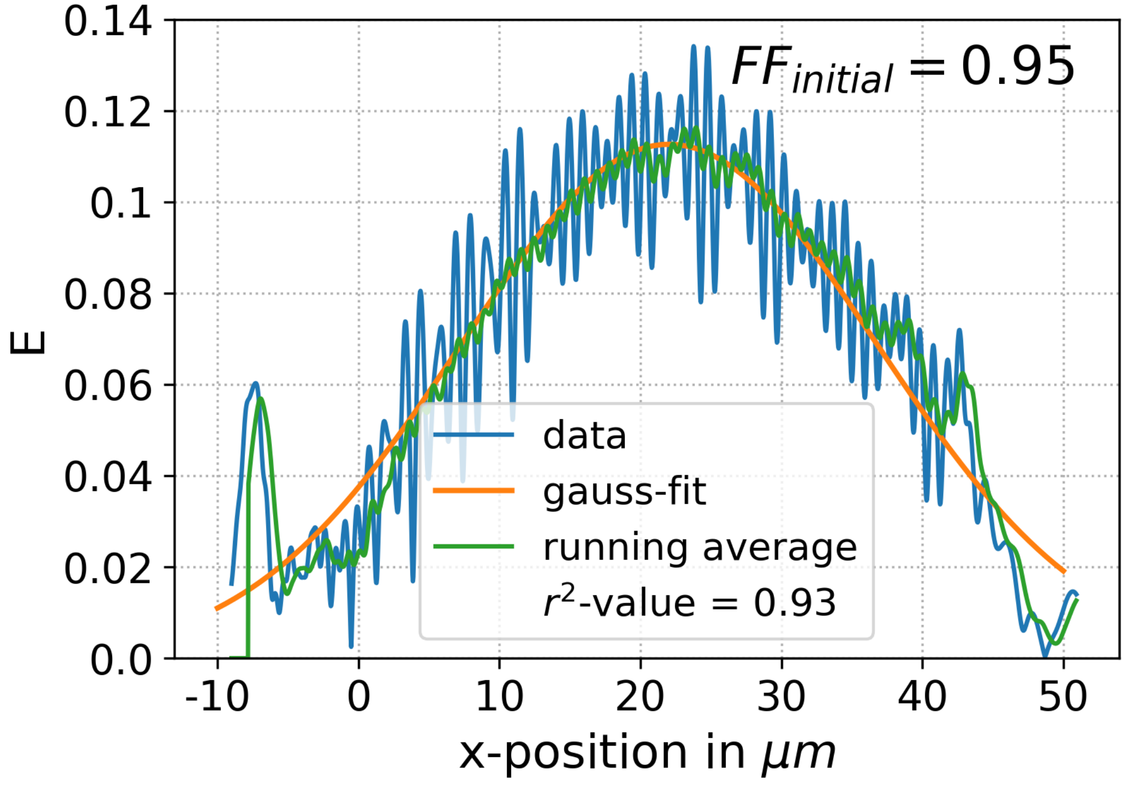
n_{tooth} = 1.697 instead of n_{tooth} = 1.68 changes the diffraction angle from θ = -5.20° to θ = -5.65°





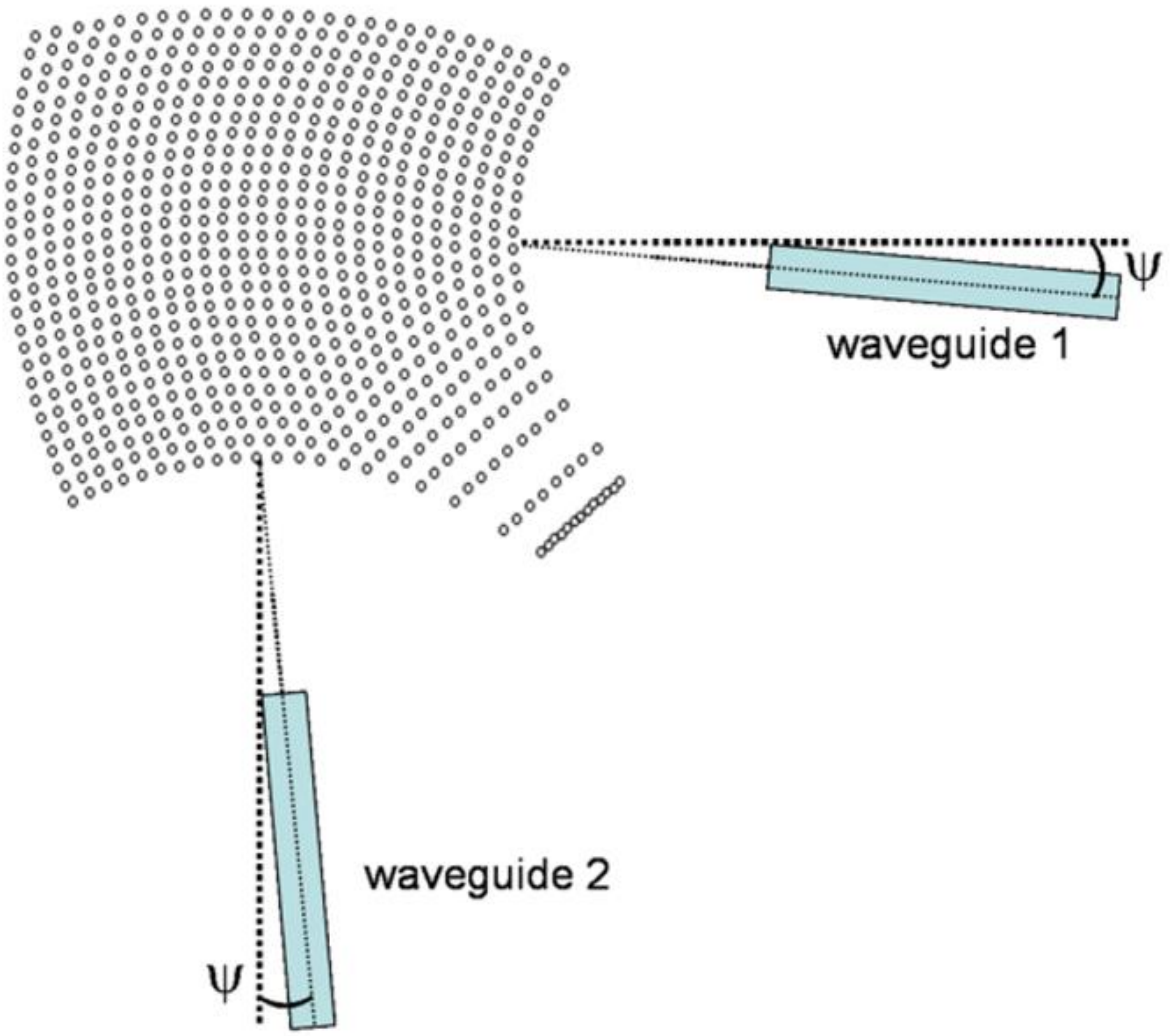
Possible improvements for the 2D GC

- Fabry-Pérot oscillations
- Increasing of the number of gratings above 50 (~ 0.3 dB improvement for 70 gratings expected)
- More complicated apodization



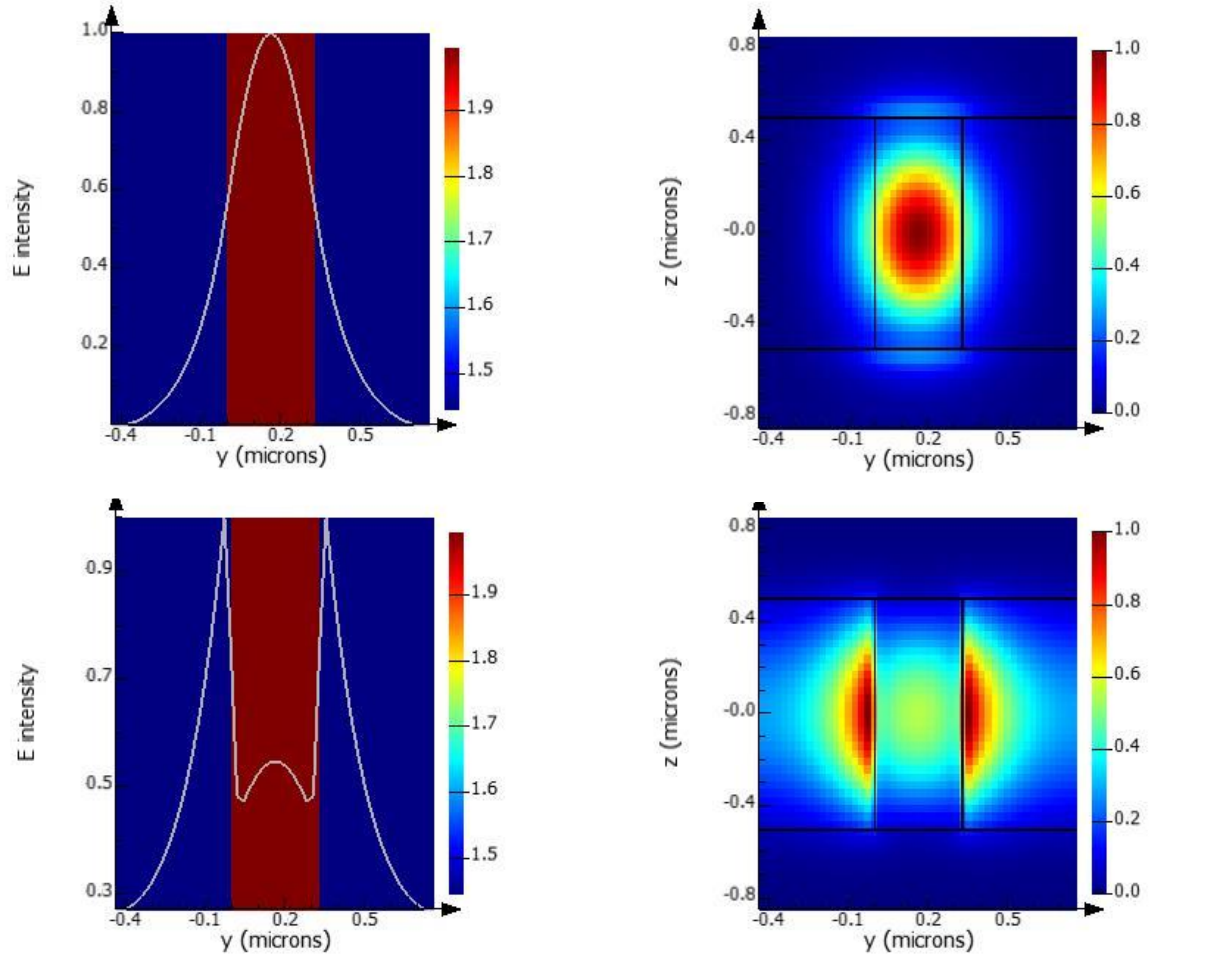
Outlook PSGC

- Scattering elements at intersections of the two GCs
- The shape of these scattering elements is crucial
- Introduction of Ψ to increase coupling efficiency

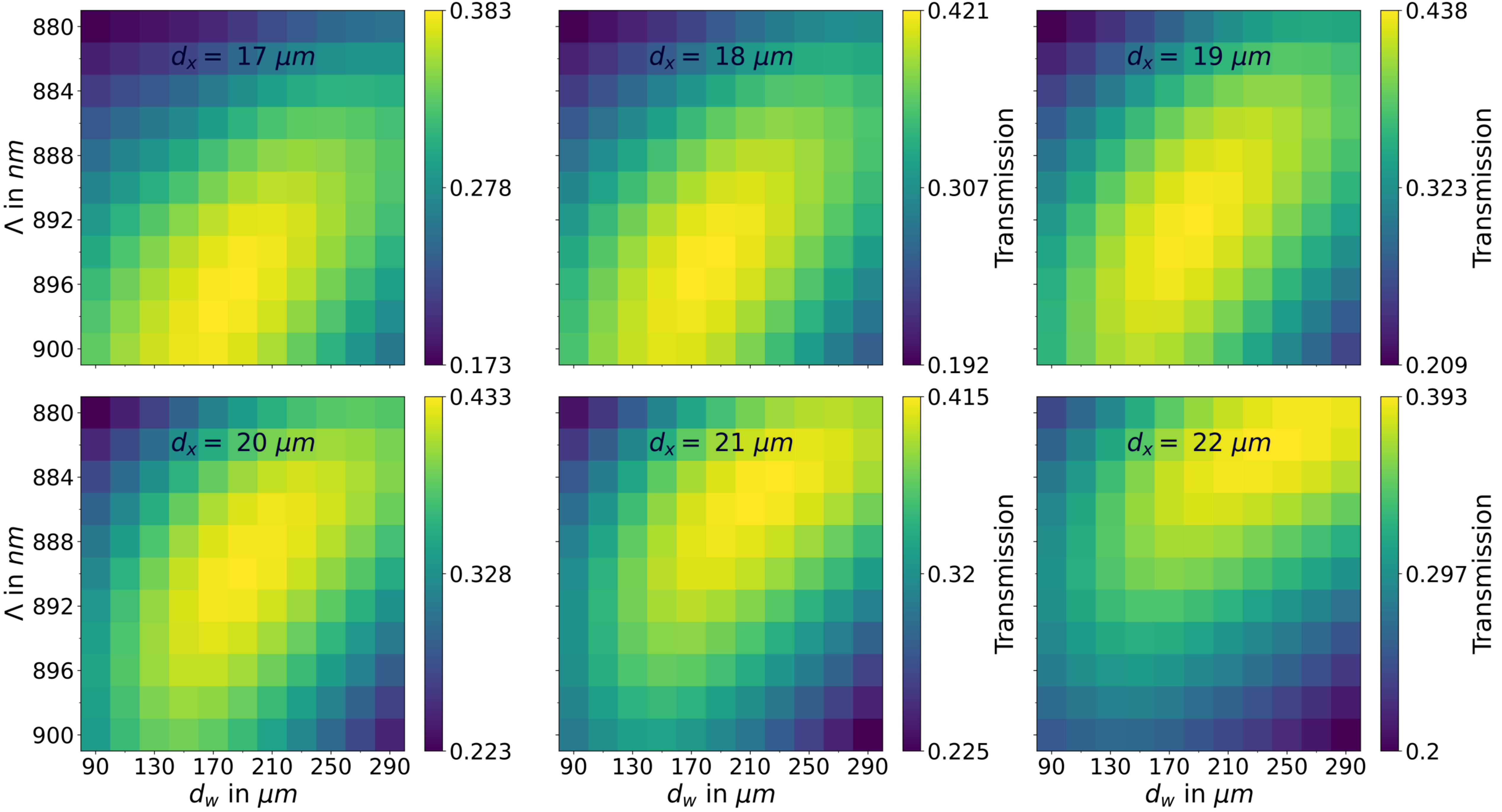


From Laere et al. (1)

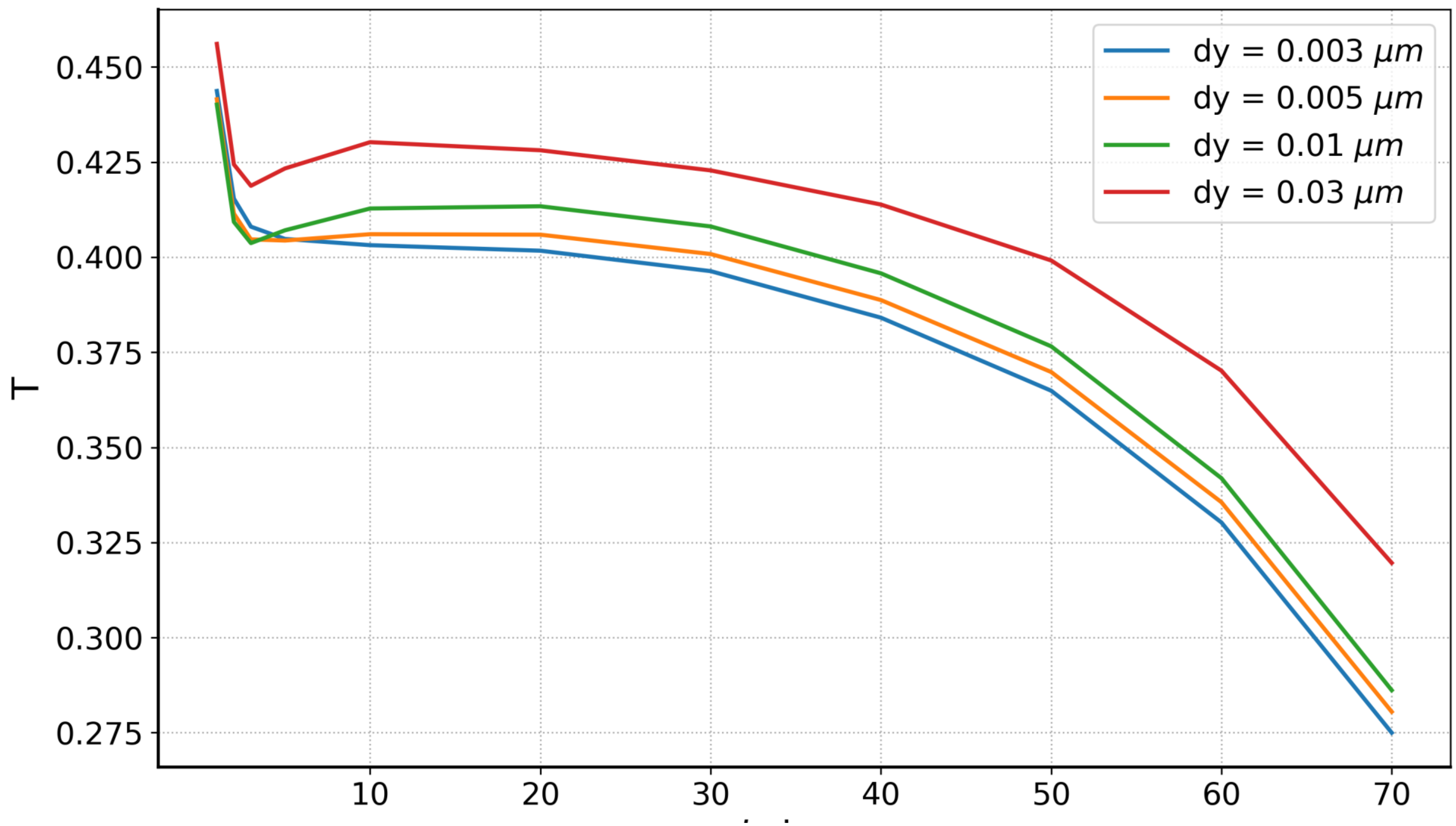
Appendices:



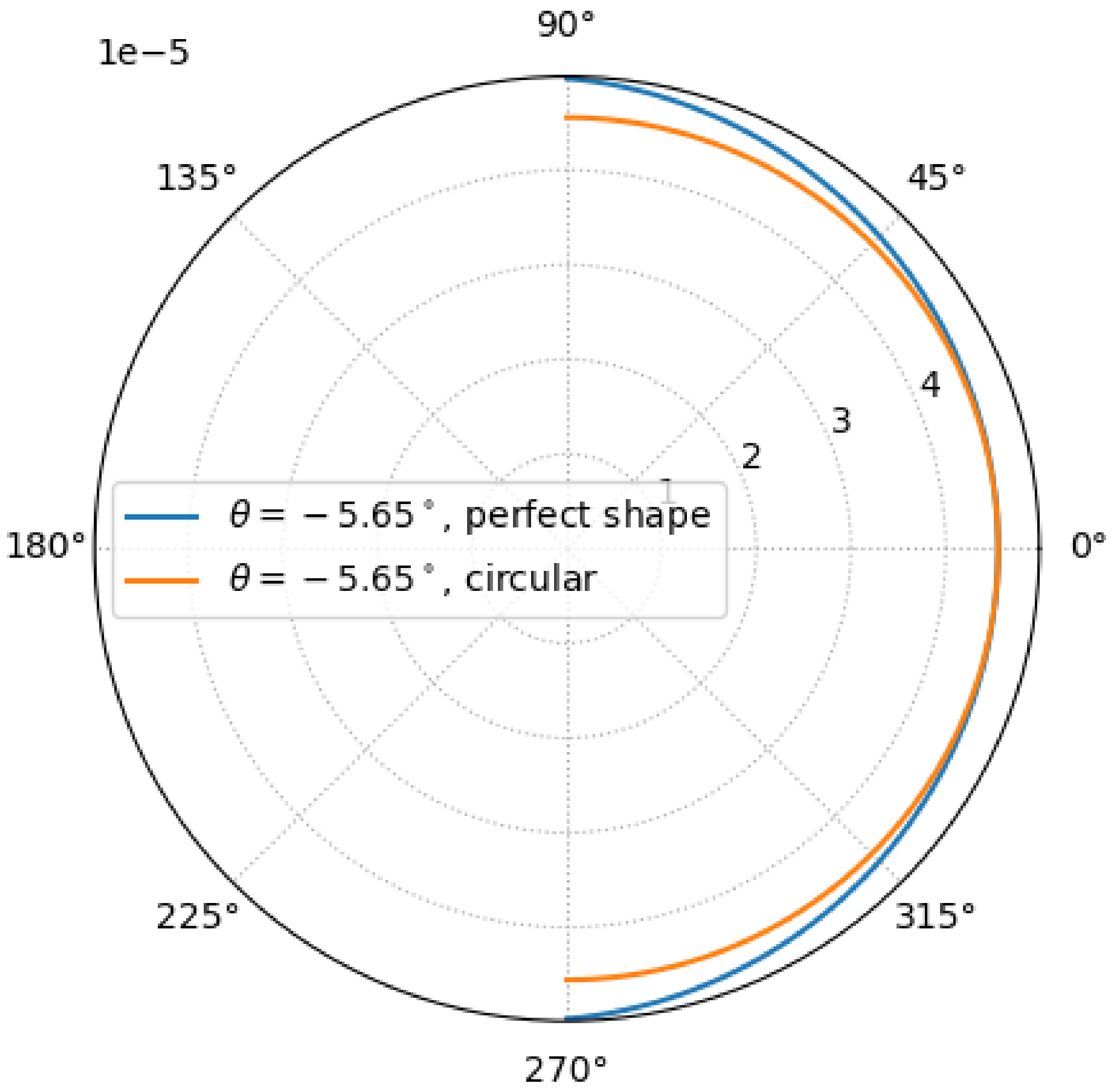
E intensity
1.0
0.8
0.6
0.4
0.2
1.9
1.8
1.7
1.6
1.5
-0.4
-0.1
0.2
0.5
y (microns)
z (microns)
0.8
0.4
-0.0
-0.4
-0.8
1.0
0.8
0.6
0.4
0.2
0.0
-0.4
-0.1
0.2
0.5
y (microns)
E intensity
0.9
0.7
0.5
0.3
1.9
1.8
1.7
1.6
1.5
-0.4
-0.1
0.2
0.5
y (microns)
z (microns)
0.8
0.4
-0.0
-0.4
-0.8
1.0
0.8
0.6
0.4
0.2
0.0
-0.4
-0.1
0.2
0.5
y (microns)

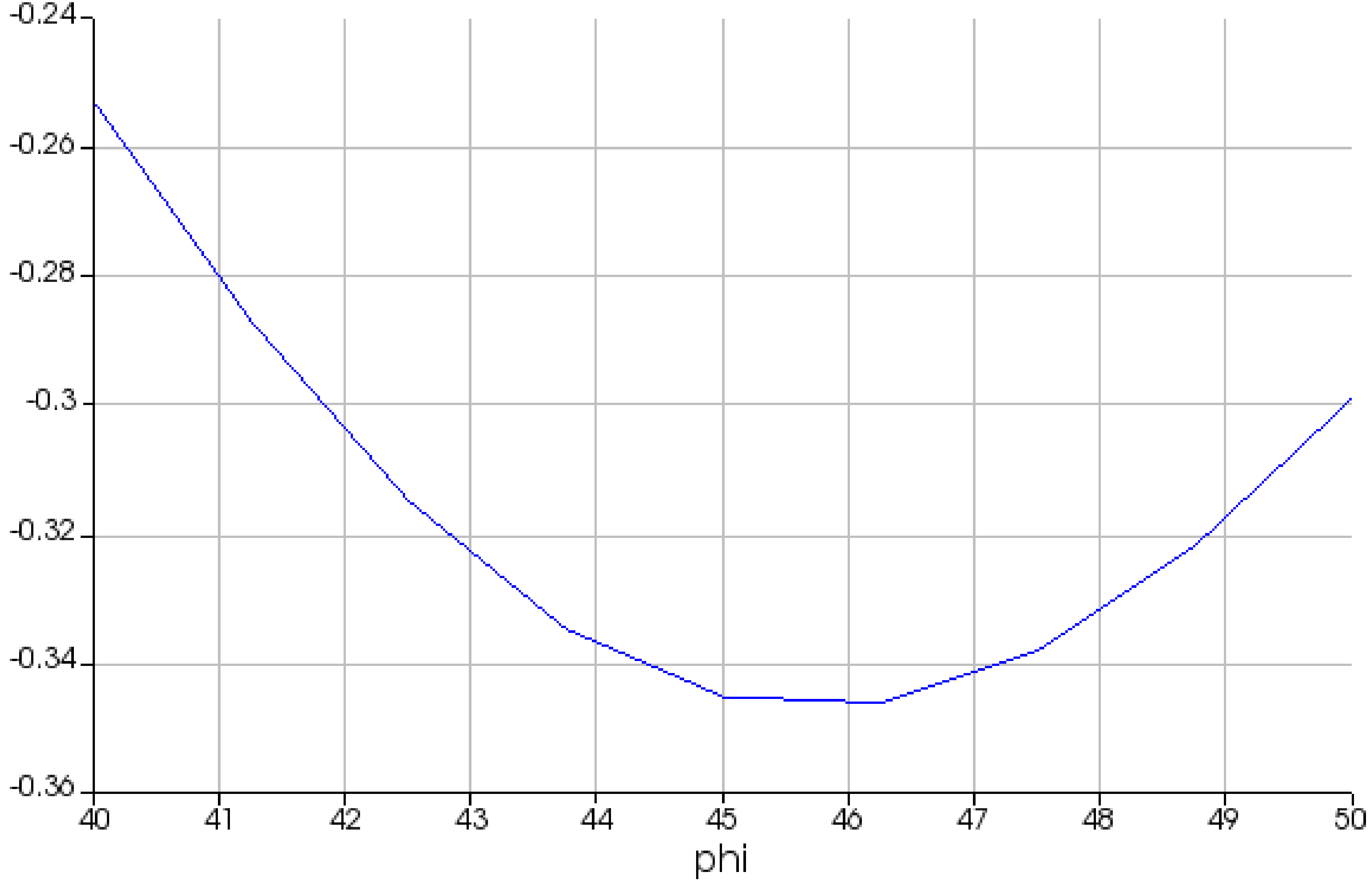


$d_x = 17\ \mu m$
$d_x = 18\ \mu m$
$d_x = 19\ \mu m$
$d_x = 20\ \mu m$
$d_x = 21\ \mu m$
$d_x = 22\ \mu m$
Λ in nm
880
884
888
892
896
900
d_w in μm
90
130
170
210
250
290
Transmission
0.383
0.278
0.173
0.421
0.307
0.192
0.438
0.323
0.209
0.433
0.328
0.223
0.415
0.32
0.225
0.393
0.297
0.2

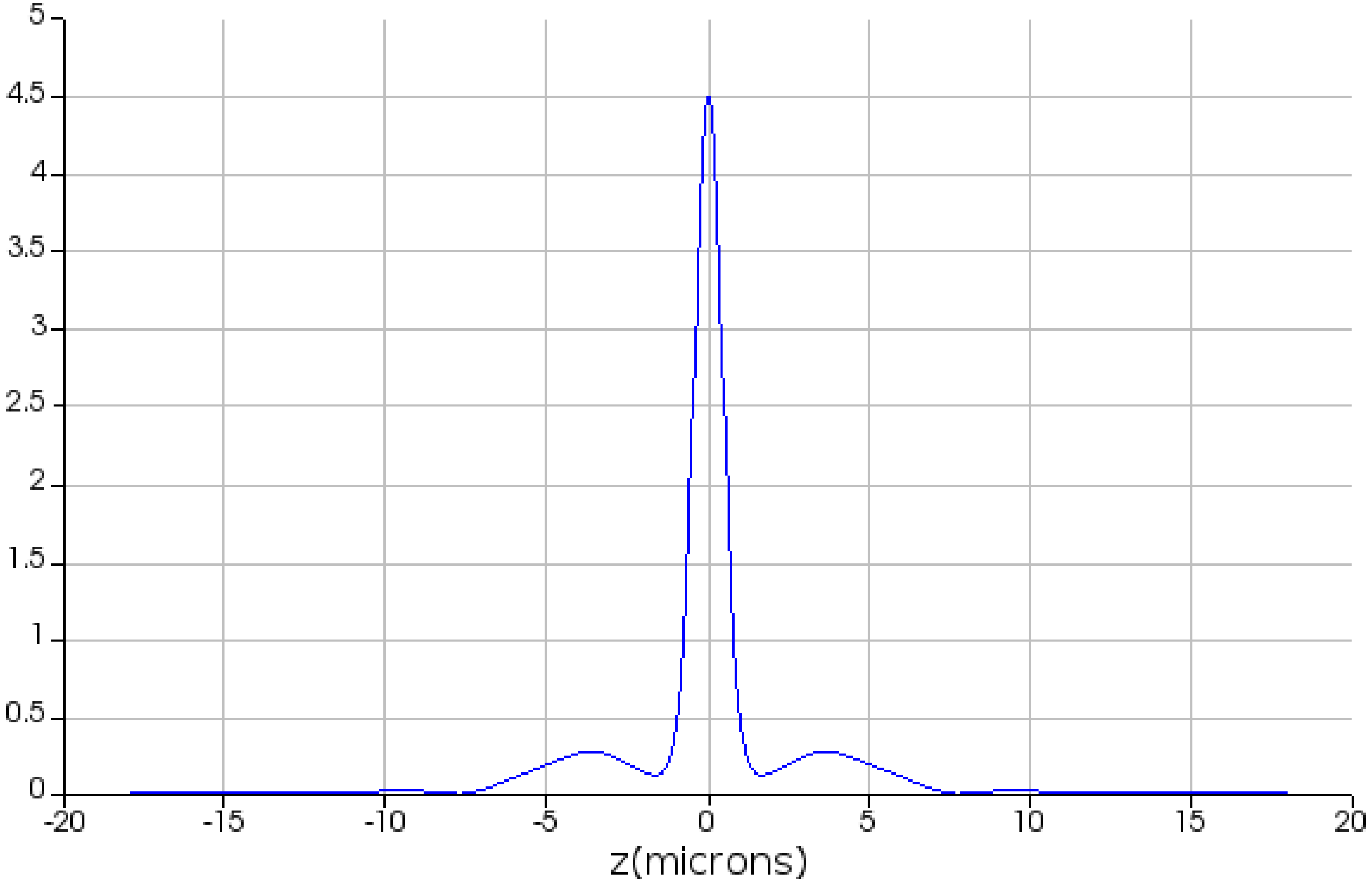


dy = 0.003 μm
dy = 0.005 μm
dy = 0.01 μm
dy = 0.03 μm
T
0.450
0.425
0.400
0.375
0.350
0.325
0.300
0.275
10
20
30
40
50
60
70

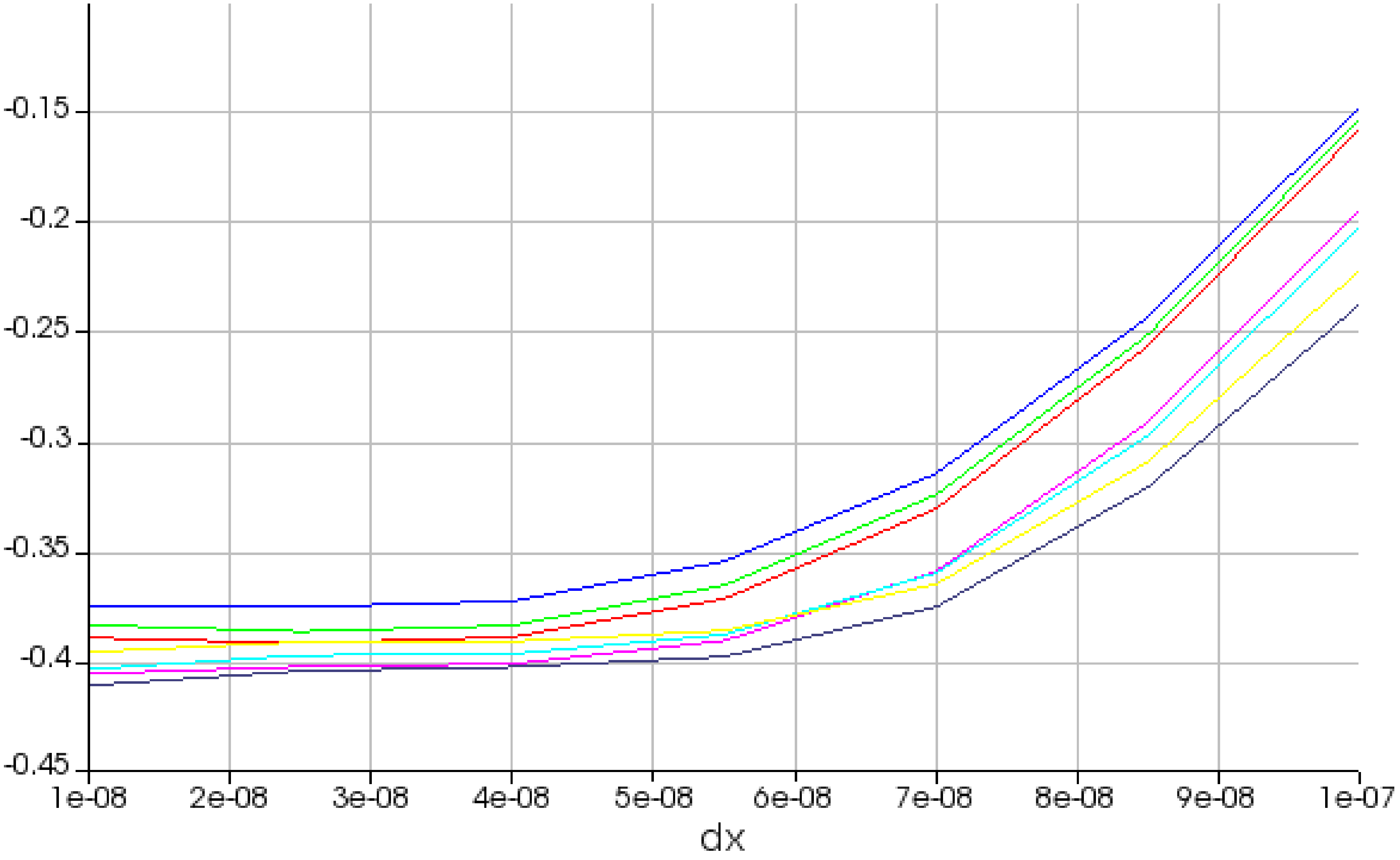

1e−5
90°
45°
135°
180°
0°
225°
315°
270°
1
2
3
4
$\theta = -5.65^\circ$, perfect shape
$\theta = -5.65^\circ$, circular



-0.24
-0.26
-0.28
-0.3
-0.32
-0.34
-0.36
40
41
42
43
44
45
46
47
48
49
50
phi



5
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
-20
-15
-10
-5
0
5
10
15
20
z(microns)


-0.15
-0.2
-0.25
-0.3
-0.35
-0.4
-0.45
1e-08
2e-08
3e-08
4e-08
5e-08
6e-08
7e-08
8e-08
9e-08
1e-07
dx

Notes